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A Fault Tolerant Deadlock-Free Multicast Algorithm for 2D Mesh Multicomputers

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Abstract

Fault tolerance is one of the most important issues that deal with the design and implementation of interconnection networks for large-scale parallel computers. That includes Multiprocessors System-on-Chip, distributed memory systems (multicomputer), cluster computers and peer-to peer communication networks. In this paper, a novel fault tolerant multicast routing algorithm, for wormhole routed 2D mesh multicomputer is presented. This algorithm is a unicast/tree based multicast routing algorithm. The proposed routing algorithm, called fault tolerant deadlock-free multicast, FTDM, works perfectly for the most common faults in 2D mesh networks, f-rings and f-chains. This algorithm is proved to be deadlock free. In FTDM no virtual channels are used. Two essential performance metrics in mesh networks, traffic steps and latency steps, are evaluated.

1. Introduction

One of the important issues in parallel computing is how to powerfully accomplish routing in a faulty network, where each element fails with various probabilities. Routing is a task where a source node sends a message to a destination node. Network topology is an important factor that affects routing algorithms.

Mesh connected networks have been widely used in most Multicomputer systems. These computers generally use the e-cube routing algorithm with wormhole switching because of its simplicity. The main idea of e-cube algorithm is to route a message first along the row and then along the column in a 2D mesh. It is important to note that e-cube provides deadlock-free shortest path routing without needing virtual channels [1]. Distributed-memory systems are the most advantageous architectures in building massively parallel computer system. These systems need switching techniques to broadcast messages among processors. The wormhole switching technique has been widely used in the design of parallel computer systems. The basic idea of wormhole routing is that a message is partitioned into flow control flits. Each flit of a message is chosen as the header flit, which is responsible for leading the message on the network. The multicast pattern, in which one processor (node) sends the same message to multiple processors (nodes), is the most fundamental communication pattern used on multicomputer. Fault tolerance is a central issue facing the design and implementation of interconnection networks for distributed-memory systems. This paper will focus on studying the fault-tolerant multicast wormhole routings in a 2D mesh networks.

2. Related work

In recent years, fault tolerant routing in direct networks has been gaining attention. The model of individual link and node failures produces patterns of failed elements. Fault regions result from the closest faulty links and faulty nodes. The three most important faults are convex, concave, and irregular. A good fault tolerant routing should be simple (low implementation cost), uses scheme few numbers of virtual channels, assures the delivery of messages, tolerates many types of fault patterns, and assures deadlock-free routing while minimizing disabled processors to ease the routing algorithm. Furthermore, all these goals should be achieved with less consideration for hardware requirement.

Boppana and Chalasani [1] have proposed an efficient technique to develop the current wormhole switched routing algorithm developed for high radix, low dimensional mesh networks for fault tolerant routing. They measured randomly located faulty blocks and fault information that uses only local knowledge of faults and tolerates non-overlapping f-rings. Their fault tolerant scheme uses these f-rings to transmit messages around fault regions. This algorithm is a modification of the e-cube algorithm and provides deadlock-free routing in mesh networks by using four virtual channels. Sui and Wang [2] have proposed an enhanced algorithm that tolerates overlapping f-rings and f-chains using only three virtual channels per physical channel. By calming the limitations on the shape of the faulty regions in [3], Boppana and Chalasani have introduced the new routing algorithm that uses four virtual channels and that tolerates many forms of f-rings, called non-convex faults.

Xiang et al [4] proposed a new deadlock-free adaptive routing scheme for 3D meshes using only two virtual channels per physical channel by building full use of the idle channels. This new deadlock-free adaptive routing scheme is also extended to *n*-D meshes and derived from the planar network fault model. Also, Xiang [5] introduced a deadlock-free routing scheme for meshes derived from a new virtual network partitioning scheme, called channel overlapping. According to their new virtual network partitioning scheme there are two virtual networks that can share some common virtual channels. This fault tolerant deadlock-free adaptive routing algorithm is also extended to the one in an n-D mesh using two virtual channels per physical channel. In this algorithm fault blocks are constructed inside divide planes, which turn on a lot of globally unsafe fault free nodes.

Wu and Chen [6] proposed a fault tolerant tree-based multicast routing algorithm for 2D meshes derived from the conception of the extended safety level which is a vector associated with each node to capture fault information in the neighborhood. In this algorithm each destination is reached through the smallest number of hops. Also, this algorithm can be easily implemented by pipelined circuit switching derived from limited global information with a simple model. Chang and Chiu [7] proposed a fault tolerant multicast unicast-based routing algorithm, FT-cube2, in 2D meshes. In the FT-cube2, the well-known e-cube routing algorithm is improved in order to deal with multiple fault regions in 2D meshes using only two virtual channels per physical channel. In FT-cube2 routing algorithm, normal messages are routed via e-cube hops. A message is misrouted on an f-ring or f-chain to destinations along clockwise or counterclockwise directions.

The rest of this paper is organized as follows. Section 3 gives background of the work. Section 4 presents the proposed fault-tolerant routing method and the proof of deadlock freedom.

Section 5 shows results and discussions. Finally in Section 5, some concluding remarks are made.

3. Background

In this section, we first briefly review the mesh topology. We then give an introduction to multicast routing algorithms.

3.1. Mesh topology

Mesh network topology is one of the most important interconnection networks. Distributed memory systems using mesh topology as their essential architecture have been around for years, because of their simplicity, reliability and good scalability. Also, their significance in achieving high performance, fault tolerant computing for mesh topology has been the focus of research. A 2D mesh with n x n nodes has an internal node degree of 4 (four neighbors), one in each of four directions: East, south, west, and north. A number of large research and commercial multicomputer systems have been built based on 2D and 3D mesh topologies, including Illiac IV, MPP, DAP, CM-2, Intel paragon , Goodyear MPP [8] and Blue Gene Supercomputer [9].

A very important area of mesh fault tolerance is its ability to route packets from a source node to a destination node, while avoiding all faulty nodes in the system. Routing is a process to send packets (message) from a source node to a destination node, passing some intermediate nodes. Most routing algorithms are either deterministic or adaptive. Deterministic routing algorithms use one path to route packets (message) from a source node to a destination node, and are used on most commercial systems because of its deadlock freedom and ease of implementation. Adaptive routing makes use of many different paths to route packets. XY routing is an example of dimension order routing used in 2D mesh networks. In XY routing, the packet is routed in X dimension first and then in Y dimension. Unluckily, XY routing is not fault tolerant, and it cannot tolerate any fault, but can use it on a non faulty region as a deadlock-free routing algorithm.

3.2. Multicast routing algorithms

There are three basic types of multicast routing algorithms: unicast-based, tree-based and path-based [10], but in this paper we construct a new type, which is a compromise of tree based and unicast based, called unicast/tree based routing. In unicast based algorithms, a source node routes a message to the destinations by sending a series of separate unicast messages to each destination. It needs a startup for each destination. The separate addressing is a unicast based multicast routings, in which the source node sends directly a separate copy of the message to every destination node [11].

Tree based routings tries to send the message from source to all destinations in a single multi-head worm that splits at some routers and replicates the data on multiple output ports. Path based routing allows a worm to hold sorted list of several destination addresses in its header flits. They use a simple hardware mechanism to allocate routers to absorb flits on interior channels while concurrently forward copies of the flits on output channels enroute to the residual destinations.

4. The proposed algorithm (FTDM)

All fault tolerant routing algorithms which were proposed recently concentrate on unicast-based multicast algorithms. Unicast-based algorithms require a startup time for each destination and this require more work. Also, they are incompetent because they permit a message to be delivered to only one destination, which leads to multicast operations being implemented as multiple phases of multicast message exchange. So, contention freedom must be guaranteed not only among the worms of a given phase, but also among worms in different phases.

In this section, a new fault tolerant deadlock free multicast routing algorithm, FTDM, for 2D meshes is introduced. FTDM is a unicast/tree-based multicast algorithm, which attempts to deliver the message to all destinations in two phases. In the first phase the message is delivered as a unicast-based to X-coordinate nodes (nodes $(0, y_{bi})$ in case of odd rows or $(m-1, y_{bi})$ in case of even rows) of each *true fault regions* at these nodes; *central nodes*. We consider each node of them as a source node that has a message with header containing destinations in the three locations around the fault. In the second phase, the message is delivered from the central nodes in a tree-based fashion, which attempts to route the message to all destinations in a single multi- head worm that splits at some routers and replicates the data on multiple output ports.

To define the path routing functions, which determines the next node for which the path of FTDM will be visited, some definitions are introduced:

1) Let $f_{bi}= (x_{bi}, y_{bi})$, and $f_{ei}= (x_{ei}, y_{ei})$ be the coordinates of each fault.
2) The fault region number *i*, F_i, is described by two nodes, f_{bi}, f_{ei}, where f_{bi} is located in the southwest corner of the fault region, while f_{ei} is located in the northeast corner of the fault region,
$$F_i = \{(x, y): x_{bi} < x < x_{ei} \wedge y_{bi} < y < y_{ei}\}.$$
3) Width of a fault region F_i is defined as follow: $d_{Fi}=| x_{ei} – x_{bi} |$
4) The variable d_x is equal to 1 if the direction of the message path is from west to east or -1 if it is from east to west.
5) *LN* is the label of last node, (x_{ei}, y_{bi}), of a fault region which the message path visits. The value of LN is zero if the message path is in a non-fault region, while it is non zero if the message path is in a fault region.
6) Let L_1, $L_2$and L_3 are three locations around each true fault regions as in figure 1, and L_4 is a location in case if the 1st fault region is an f-ring. In figure 1 we define three fault regions F_1, F_2 and F_3. Also, the notation $L_{A,B}$ means location A for fault number B (i.e. $L_{3,1}$ means location three for the 1st fault region, F_1.)
7) *True fault regions* are the main fault regions which have three locations around them and may have other fault regions on locations, L_3 or L_1, with $f_{bi}= (x_{bi}, y_{bi})$, and $f_{ei}= (x_{ei}, y_{ei})$ less than it.
8) *Central nodes* are the nodes which the source node sends a copy of a message in the first phase in a unicast fashion,
9) Consider a source node as one of the central nodes if the first fault region is f-ring.

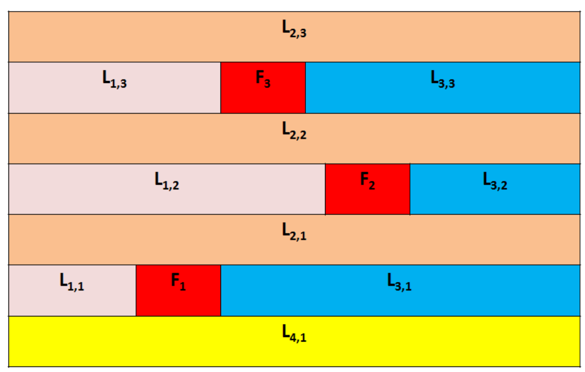

Figure 1. Locations around fault regions

4.1. Routing functions

FTDM assigns a label for each node based on the position of that node in a Hamiltonian path. The *Hamiltonian* path in a network is an undirected path that visits each node in a graph just once where the first node in the path is labeled *1* and the last node in the path is labeled *N,* where *N* is the network size [12]. The label assignment function Q for an $m \times n$ 2D mesh using a Hamiltonian path can be expressed in terms of the x- and y-coordinates of nodes as follows:

$$Q(p_i) = Q(x_i, y_i) = \begin{cases} y_i \times n + x_i + 1 & y_i \text{ is even} \\ y_i \times n + n - x_i & y_i \text{ is odd} \end{cases}$$

FTDM creates the routing decision at each sending node. The path followed by a message in the first phase is simply unicast-based in which a source node sends a separate message to each central node beside a copy to L_4 in case the first true fault region is f-ring using XY routing algorithm. The path followed by a message in the second phase is defined by one of the two routing functions. Each function is defined as a function of the node currently holding a message, and the destination node of this message. The function returns a neighboring node of the current node to which the message must be forwarded. Let c be a current node, and d is a destination node.

The first routing function used in FTDM is defined as:

R (c, d) = w, where

$$Q(w) = \begin{cases} \max\{Q(z): Q(z) \le Q(u)\} \text{ if } Q(c) < Q(d) \\ \max\{Q(z): Q(z) \ge Q(u)\} \text{ if } Q(c) > Q(d) \end{cases}$$

and z is a neighboring node of c

It was proved in [12] that for two arbitrary nodes *c* and *u* in a 2D mesh, the path selected by the routing function R is the shortest path between them. As proved in [12], this routing function is deadlock-free even using the path based on facility. FTDM which uses the routing function R in each region does not contain any fault nodes.

2) The second routing function used in FTDM at a fault region F_i is defined as:

R′(c, d) = w, where

$$w = \begin{cases} (x_c, y_c-1) & \text{if } x_d = x_c \\ (x_c, y_c+1) & \text{if } x_d = x_c + d_x \times d_{Fi} \\ (x_c + d_x, y_c) & \text{otherwise} \end{cases}$$

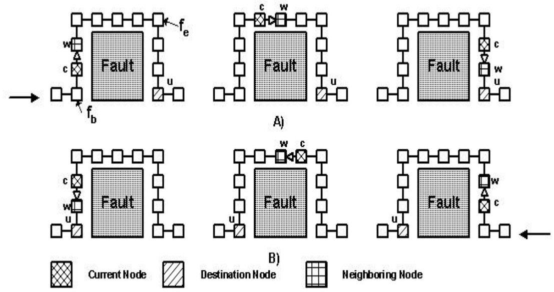

Figure 2. The routing path using R'

Algorithm FTDM

Input: The message *msg*, Label node LN, central nodes CN_k, destination set D, and fault region F_i .

Output: $\forall\ d_j \in D$, Receive(d_j , *msg*)

Procedure:

[1]/* Phase 1 (unicast-based): Send copies of message to CN_k

[a] If $c = d_1$ then

a. 1) D = D-{c}

a. 2) Receive(c, *msg*)

[b] If D = ϕ then stop

[c] Send separate messages to CN_k using XY routing.

[d] Modify header of messages, *msg*, and put in each header D_k destinations, which k is the number of central nodes (plus one if first fault is f-ring)

[e] Let each CN_k as a new source node

[f] Go to phase 2

[2]/* Phase 2 (tree-based): Send *msg* using R and R' functions

[a] If $c = d_1$ then

a. 1) D = D-{c}

a. 2) Receive(c, *msg*)

[b] If D = ϕ then stop

[c] At each new source node, send two copies of message, *msg*

c. 1) 1st copy contains destinations on L_1 and L_2 using R

c. 2) 2nd copy contains destinations on L_3. Using R' to route a message around the fault region until the message reach to LN, and then use R.

c. 3) If L_3 have another faults then recursively apply FTDM.

[d] Repeat the above steps until each destination in the message header is reached.

FTDM uses the routing function R' in fault regions only. Figure 2 illustrates the different cases of the routing function R' and the way of its work around the fault region. The direction of the message path may be from west to east, figure 2(A) or from east to west, figure 2(B). It is clear that, the path selected by the routing function R' is the shortest path between the two nodes c and u. Also, it is clear that, the routing function R' is deadlock-free, because it works on three boundaries only of each fault region, i.e., the cycle is not complete.

Lemma: FTDM algorithm is deadlock-free

Proof: There are two phases as following:

Phase 1: Unicast-based multicast routing

The separate addressing is one of the unicast-based multicasting techniques, which is proven a deadlock-free [11], because in separate addressing, the source node sends directly a separate copy of the message to every destination node, then no cyclic dependency can be created among the channels.

Phase 2: Tree-based multicast routing has two cases and they are as follows:

Case 1: Nonfault regions

Because a cyclic dependency among resources is a necessary condition for deadlock, since a message is routed at any node according to the routing function R, which is proved deadlock-free [13], and monotonic order of requested channels is guaranteed, therefore, a cycle cannot exist within this path in the network; hence no cyclic dependency can be created among the channels.

Case 2: Fault regions

Since a message is routed at any faulty nodes according to routing function R´, and a message never visits an f-ring and f-chain more than twice (at most as a row message and once as a column message), then, a cycle cannot exist within this path in the network.

Hence, FTDM algorithm is proved deadlock-free.

5. Results and Discussions

A simulation study has been conducted to test the proposed new fault-tolerant multicast routing algorithm. To evaluate the performance of the proposed routing algorithm, and to compare the performance of the FTDM and FT-cube2 routing algorithms, simulations on a 50×50 2D-mesh are conducted, double channels were used. The two algorithms were written using C++ language and were implemented on a PC. In this section, we present the simulation results and analysis. In the simulation, wormhole routing is chosen as the switching technique and the routing algorithm is also applicable with other switching techniques. The notation F is used to represent the number of fault regions, R is the number of rows, and C is the number of columns. This configuration creates different networks with a number of processors ranging from 100 to 1080. The average number of destinations is ranging from 10 to 100 and using three fault regions.

5.1. Latency steps and Traffic steps analysis

In this subsection, two essential performance metrics in direct networks, network latency steps and network traffic steps, are calculated. The network latency step is the greatest number of channels which the message takes to reach its destinations. The network traffic step is the total number of channels used to deliver the message to all destinations. They affect the overall performance of the multicomputer system and the granularity of parallelism that can be exploited from the system [14].

Now, the network latency steps and network traffic steps are calculated for FTDM and FT-cube2 routing algorithms. The following formulas can be used to calculate the network latency steps for FTDM.

Our partitioning of the 2D mesh around each fault regions into L_{i1}, L_{i2}, L_{i3} and L_4, will result in partitioning the destinations D into D_{i1}, D_{i2}, D_{i3},and D_{i4} respectively where i is ranging from 1 to F, and F is number of fault regions. In addition, (c_X, c_Y) is the coordinate of central node.

1) $\text{dist}(d_i, d_{i-1}) = |x_{di} - x_{di-1}| + |y_{di} - y_{di-1}|$
2) $\text{Lat}(D) = \sum_{i=1}^{|D|} \text{dist}(d_i, d_{i-1})$

Which is dependent on the start coordinates and end coordinates for each location.

3) $D_i = \{(x, y) : (x, y) \in D \wedge x > x_{bni} \wedge y < y_{ei}\}$
4) $L_{i1} = \text{Lat}(D_{i1}) + |(c_X - x_{di})| + |(c_Y - y_{di})|$,
5) $OO_i = |X_{end} - X_{start}| - 1$, Where $X_{start} = 0$ and $X_{end} = x_{bi} + 1$
6) $UU_i = y_{bi} + 1$
7) $Lf_i = 2*|(y_{ei} - y_{bi} - 1)| + |(x_{ei} - x_{bi})|$
8) $L_4 = \text{Lat}(D_{i4}) + |(S_X - x_{di})| + |(S_Y - y_{di})|$
9) $L_{i2} = \text{Lat}(D_{i2})$,
10) $L_{i3} = \text{Lat}(D_{i3})$
11) $\text{Traffic}_{(i)} = L_{i1} + L_{i2} + L_{i3} + OO_i + UU_i + Lf_i$
12) $LP_{(i)} = L_{i1} + L_{i2} + UU_i$
    Where LP is the left path
13) $RP_{(i)} = L_{i3} + OO_i + UU_i + Lf_i$
    Where RP is the Right path

The latency step of FTDM, FTDM_Latency, is given by:

$$\text{FTDM\_Latency} = \text{Max}(LP_{(i)}, RP_{(i)}, L_4) \quad (1)$$

The traffic steps of FTDM, FTDM_Traffic, is given by:

$$\text{FTDM\_Traffic} = \text{Traffic}_{(i)} + L_4 \quad (2)$$

The latency step of FT-cube2, FT_Latency, is given by:

$$\text{FT\_Latency} = \text{Max}\{\text{Flat}_i, 1 \le i \le |D|\} \quad (3)$$

Where $\text{Flat}_i = |x_{di} - S_x| + |y_{di} - S_y| + 2*|y_{ei} - y_{bi}|$

The traffic steps of FT-cube2, FT_Traffic, is given by:

$$\text{FT\_Traffic} = \sum_{i=1}^{|D|} \text{Flat}_i \quad (4)$$

5.2. Latency steps and Traffic steps results

The equations from 1 to 4 are used to calculate network latency steps and network traffic steps for both algorithms in 2D mesh. Figures 3 and 4 show the results. The continuous line represents results of FTDM, while the dotted line represents results of FT-cube2.

Figure 3 plots the latency steps for various values of the average number of destinations, ranging from 10 to 100. The figure shows that, the latency steps computed by FTDM increases as number of destinations increases. The increase in latency steps will begin to be less significant as the number of destinations increase. The increase is not affected by type of the fault region (f-ring and f-chain). The latency steps computed by FT-cube2 is nearly constant as number of destinations increases. This is because FTDM is a unicast/tree-based multicast routing algorithm while FT-cube2 is unicast-based multicast routing algorithm.

Figure 4 plots the traffic steps for various values of average number of destinations, ranging from 10 to 100. The figure shows that, the traffic steps computed by FTDM is nearly constant (slight increase) as number of destinations increases. The traffic steps computed by FT-cube2 increase as the number of destinations increases. The increasing rate of the traffic steps computed by FT-cube2 is large because each destination needs a separate message path.

In all tested cases, the network traffic steps computed by FTDM is less than that computed by FT-cube2.

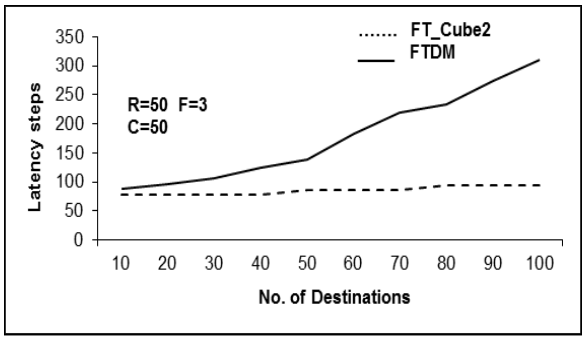

Figure 3. Latency Steps Vs. No. of Destinations

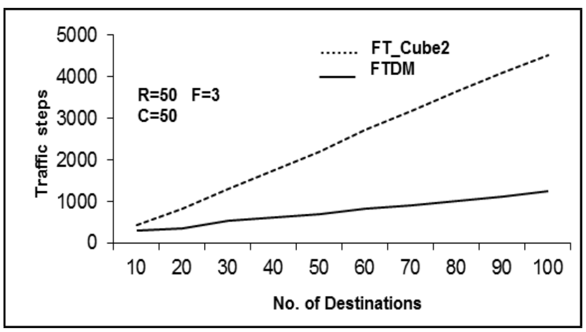

Figure 4. Traffic Steps Vs. No. of Destinations

6. Conclusions and Future work

In this paper, we have proposed a fault-tolerant routing algorithm for 2D mesh. The proposed algorithm, FTDM, can tolerate convex faults without using virtual channels. Because fault information is distributed to a limited number of nodes, FTDM is a limited-global-information-based multicasting algorithm which is a compromise of local-information-based approach and global-information-based approach. Also, FTDM tolerates f-chains in meshes. We show that the proposed algorithm does not lead to deadlock with any number of non-overlapping f-regions. Our simulation results show that FTDM tolerates multiple faulty blocks using only no virtual channels, and has better performance than FT-cube2 in terms of traffic steps.

In this work we take into consideration the effect of the number of destinations. We will continue to investigate the effect of the fault size and the number of faults.

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A Stepwise Method of Using Exploratory Factor Analysis in Creation of a Lean Survey

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Abstract

Exploratory factor analysis (EFA) is a part of the construct validation process most commonly used for data reduction in social science research. In published studies, EFA was used for a variety of applications, including developing an instrument for the evaluation of school principals (Lovett, Zeiss and Heinemann 2002), assessing the motivation of Puerto Rican high school students (Morris, 2001), and determining what types of services should be offered to college students (Majors and Sedlacek 2001). Factor analysis assumes that underlying dimensions or factors can be used to explain complex phenomena. The goal of factor analysis is to identify not-directly-observable factors based on a larger set of observable or measurable indicators (variables) (Lingard and Rowlinson 2006). This paper explains a stepwise method to quantitatively and qualitatively assess the results of the EFA technique. To realize a factor structure that can be explained and justified. A lean implementation assessment survey was used in this study. The survey, which had five factors with 29 questions, was distributed electronically and received 120 responses which were analyzed using EFA. There is a great deal of subjectivity regarding the criteria for determining the number of latent variables that are extracted for an EFA analysis (Hair Jr., et al. 1992). The method used in this paper helps explain how EFA could be used to help validate surveys.

1. Introduction

Ever since the publishing of the book "Machine that Changed the World" (Womack, Jones and Roos 1990), manufacturing has seen overall improvement. This book described studies that had been compiled from 5 years of industry research that showed methods and approaches that could be used to eliminate waste and help in continuous improvement. Many studies have followed since, but there has been little research done on how to measure the success of Lean implementation. The few tools that are available for public use are used by a third-party agency that usually is involved in the training as well. This has led to few researchers studying and presenting ideas by which Lean assessment could be accomplished. None of the assessments are simple to use and usually are expensive to implement. To fulfill this need, an assessment tool was created that uses the Lean principles presented by Womack and Jones, which was elaborated in their book 'Lean Thinking' (Womack and Jones 1996). This assessment tool was survey-based which was created using 29 questions that would help measure these 5 principles.

The tool was content validated by 5 Lean experts and then administered to over 100 Lean practitioners to help validate the tool for construct validation purposes. As a part of the construct validation process, Exploratory Factor Analysis (EFA) was executed on the data collected. The EFA helps understand the grouping of data based on a covariance structure. Several iterations of EFA were conducted to arrive at a grouping of variables that best defined a group of questions under principle. This paper explains the various steps in involved in arriving at this grouping based on this rationale.

2. Theory Base for Research

The concept of Lean is simple: remove 'waste' from a system resulting in reduction of lead time involved for completion of fulfillment of a customer demand or order on a regular basis. In this context, 'waste' is any 'non-value added activity'. Value is defined as something the customer is willing to pay for. Therefore, if the customer is not willing to pay for something, it is a waste or a non-value added activity. Today, Lean is utilized in a wide range of industries, nonprofit organizations, government agencies, healthcare, and organizations in other areas as a means for producing goods and delivering services that create value for the customer with a minimum amount of waste and a maximum degree of quality (Harbour 2002).

In a traditional business approach the customer was treated as an entity at the bottom of the chain. In Lean the customer is treated as part of the product life cycle. The customer's needs are studied upfront and the product is made based on their needs. The principles of Lean have been around for more than 100 years. Henry Ford's concept of the 'Assembly Line' was considered to be the first advent of Lean principles (Ohno 1988). In the early 90's, Womack, Jones and Roos wrote the book, "Machine that changed the world", and changed how TPS was learnt and understood in a western environment. Numerous researchers have tried to teach and profess Lean using the principles of Womack and Jones in their book, "Lean Thinking" (Womack and Jones 1996).

This research delves in to creation of a tool that enables assessment of Lean implementation using employee perception. To validate the survey, statistical analysis was completed. Statistical analysis such as Factor analysis, Structural Equation Modeling (SEM) and Reliability Analysis would be more robust if the sample size is as large as possible, at least greater than hundred, which would help to make definitive conclusions and recommendations.

Construct Validity of the survey categories is a key step making a survey legitimate. Construct Validity could be defined as; "the extent to which a measurement corresponds to theoretical concepts (constructs) concerning the phenomenon under study; for example, if on theoretical grounds, the phenomenon should change with age, a measurement with Construct Validity would reflect such a change (Duffus, Nordberg and Templeton 2007)". Construct Validity seeks agreement between a theoretical concept and a specific measuring device or procedure. Construct Validity can be broken down into two sub-categories: Convergent Validity and Discriminate Validity. Convergent Validity is the actual general agreement among ratings, gathered independently of one another, where measures should be theoretically related. Discriminate Validity is the lack of a relationship among measures which theoretically should not be related (Howell, et al. 2005). It can be also defined as, "How well a test or experiment measures up to its claims. Discriminate Validity refers to whether the operational definition of a variable actually reflects the true theoretical meaning of a concept" (Shuttleworth 2009). There are 3 steps to determining whether research has content validity; first, the theoretical relationships must be specified. Second, the empirical relationships between the measures of the concepts must be examined. Third, the empirical evidence must be interpreted in terms of how it clarifies the Construct Validity of the particular measure being tested (Carmines and Zeller 1979).

Construct Validity is important in studying and understanding how the various questions under each category help in answering that given category and to what extent of accuracy that each of them do. SPSS software is used to provide us with the result which in turn enables us to make conclusions on the questions answering that attribute. Principal Component analysis and Factor analysis could be simply defined as, "a statistical approach that can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their underlying dimensions". The primary objective is data reduction; to find a way to condense, with minimal loss of information, the information contained in a number of original variables into a smaller set of variables (Hair, et al. 1998).

3. Methodology

The primary method used to examine Construct Validity for this study is to conduct factor analytic procedures to analyze interrelationships between data. The factor analysis results support Construct Validity if the factors identified correspond to the scales of the instrument. Factor Analysis is multivariate statistical method of data reduction. For example, if one has to study a large number or variables using a select few key variables, this method could be used. Another way of explaining this is as follows; Factor analysis is a statistical method used to examine how underlying constructs influence the responses on a number of measured variables. The Kaiser rule could be used as starting point for the analysis. Henry Kaiser suggested a rule for selecting a number of factors *m* less than the number needed for perfect reconstruction: set *m* equal to the number of Eigen values greater than 1 (Kaiser 1960). This rule is often used in common factor analysis as well as in PCA. Several lines of thought lead to Kaiser's rule, but the simplest is that since an Eigen value is the amount of variance explained by one more factor, it doesn't make sense to add a factor that explains less variance than is contained in one variable. Since a component analysis is supposed to summarize a set of data, to use a component that explains less than a variance of 1, is like writing a summary of a book in which one section of the summary is longer than the book section it summarizes, which is unreasonable. However, Kaiser's major justification for the rule was that it a substitute for the ultimate rule of doing several factor analyses with different numbers of factors, and seeing which analysis made sense. That ultimate rule is easier today than it was a generation ago, so Kaiser's rule seems obsolete (Darlington 1997). Care should be taken that the model should also make sense based on the grouping recommended. The grouping of the variables should make sense in reality and should not be used as a hard benchmark for creating categories. If the grouping does not make sense the model is further reduced. Most literature nowadays do not consider Kaiser's rule to be valid and therefore use it with caution as a justification for a final model.

A rotation method is usually applied to the factor structure for better clarity of factor structure. The need for rotation is paramount to view clean loading structures. In essence rotation will enable the variables to have high loading on a single factor and minimal on the others. There are basic typed of rotation; orthogonal and oblique (Manly 2005). The most common among them the Varimax type of rotation (Osborne 2008).

Statistical Package for Social Sciences 18 (SPSS 18) and Minitab 16 were used for the analysis. Minitab 16 had any issues of not being able to deal with more than 10 variables for factor analysis. Minitab was good with its help menus to understand various functions. SPSS 18 supported any number of variables in the model, and had well formatted outputs. It was easy to navigate through the menus for both tools.

Exploratory Factor Analysis is used to understand the loading structure of the variables in the survey and determine if there are any underlying factors that can bring meaning the grouping of the variables, thus helping in the data reduction process.

The primary objectives of an EFA are to determine; the number of common factors influencing a set of measures and the strength of the relationship between each factor and each observed measure.

Some common uses of EFA are to: 1) Identify the nature of the constructs underlying responses in a specific content area. 2) Determine what sets of items “group together" in a questionnaire. 3) Demonstrate the dimensionality of a measurement scale. Researchers often wish to develop scales that respond to a single characteristic. 4) Determine what features are most important when classifying a group of items. 5) Generate “factor scores" representing values of the underlying constructs for use in other analyses.

There are seven basic steps to performing an EFA:

1. Collect measurements. Variables must be measured with same experimental units.

2. Obtain the correlation matrix. Obtain the correlations (or covariances) between each of the variables.

3. Select the number of factors for inclusion. There are situations when a specific hypothesis that will determine the number factors to include, while in other situations the final model can be used to account for as much of the covariance in the data with as few factors as possible. With 'k' measures, the largest number of factors that can be extracted is 'k'. There are a number of methods to determine the "optimal" number of factors by examining your data. The Kaiser criterion states that you should use a number of factors equal to the number of the Eigen values of the correlation matrix that are greater than one (H. F. Kaiser 1958). An Eigen value is defined by the Princeton WorldNet web as, "Any number such that a given matrix minus that number times the identity matrix has a zero determinant". The "Scree test" states that you should plot the Eigen values of the correlation matrix in descending order, and then use a number of factors equal to the number of Eigen values that occur prior to the last major drop in Eigen value magnitude (Cattell 1966).

4. Extract your initial set of factors. Software programs like SPSS and Minitab could be used to extract the factors as it is too complex to reasonably be done by hand. There are a number of different extraction methods, including maximum likelihood, principal component, and principal axis extraction. The best method is maximum likelihood extraction, unless there is a lack of multivariate normality in the measures. When the data is not normal Principal Components Method of extraction is said to be a better option (Fabrigar, et al. 1999).

5. Rotate the factors to a final solution. For any given set of correlations and number of factors there are actually an infinite number of ways that can be used to define the factors and still account for the same amount of covariance in your measures. Some of these definitions, however, are easier to interpret theoretically than others. By rotating the factors a factor solution can be found that is equal to that obtained in the initial extraction but for which has the simplest interpretation. There are many different types of rotation, but they all try make the factors each highly responsive to a small subset of items (as opposed to being moderately responsive to a broad set). There are two major categories of rotations, orthogonal rotations, which produce uncorrelated factors, and oblique rotations, which produce correlated factors. The best orthogonal rotation is widely believed to be Varimax. Oblique rotations are less distinguishable, with the three most commonly used being Direct Quartimin, Promax, and Harris-Kaiser Orthoblique (Costello and Osborne 2005).

6. Interpret the factor structure. Each of the measures will be linearly related to each factor. The strength of this relationship is contained in the respective factor loading, produced by rotation. This loading can be interpreted as a standardized regression coefficient, regressing the factor on the measures. A factor is defined by considering the possible theoretical constructs that could be responsible for the observed pattern of positive and negative loadings.

7. Construct factor scores for further analysis. Additional analyses may be performed using the factors as variables but factor scores must be constructed. The score for a given factor is a linear combination of all of the measures, weighted by the corresponding factor loading. These factor scores can then be used in analyses just like any other variable, although it should be remembered that they will be strongly collinear with the measures used to generate them (DeCoster 1998).

Factor Analysis was used to analyze the data. Factor analysis is robust to the normality assumption. Studies recommend at least 100 as a minimum sample size. A Varimax rotation would be performed to minimize the variation for all variables by rotating it to an optimal setting. A Varimax rotation is done so that there is change in co-ordinates in order to maximize the sum of variances of the squared loadings.

This survey attempts to measure the implementation of Lean at a particular workstation, department or organization. The survey was given to people who fulfilled the following requirements:

- Has undertaken or is currently undertaking a Lean implementation activity for a duration of at least 3 months
- Use that background and experience to answer the survey

From the survey sent out to various people from various industries, the data was collected and tabulated. We received 120 replies to the survey we sent, from people who were or have been a part of a Lean team. The data was coded into SPSS software to get results.

4. Results

The factor analysis was conducted on the 118 responses received from the practitioners of Lean using the online software tool, SURVEYGIZMO. The 2 responses that were omitted were responses received when a couple respondents were asked to trial the online survey method. Their critical feedback regarding survey aesthetics was very helpful. The results were downloaded in MS Excel format and copied into the SPSS 18 worksheet.

Before running the data for 5 factors, the Kaiser rule was followed for the initial structure. Factors have Eigen values below 1 were not considered. This created a model which had 8 factors and explained a total variance of about of about 69%. The factor structure was analyzed to check if the factor loadings made sense qualitatively. The factor loadings with 8 factors were inconclusive with several cross-loadings and not revealing any structure qualitatively. Even though quantitatively/ statistically grouped together, a qualitative review of the groupings did not reveal why the questions would be grouped in practice. Kaiser stated his rule was created based on a set scenario and logic, so it may not apply in all cases. He suggested that if his rule does not provide a logical grouping other possible factor structures should be studied (H. F. Kaiser 1960). Bandalos and Boehm-Kauffman (2009) further found that the Kaiser rule can overextract factors using that prinicple. Kaiser's major justification for the rule was that it matched pretty well the ultimate rule of doing several factor analyses with different numbers of factors, and seeing which analysis made sense. That ultimate rule is much easier today than it was a generation ago, so Kaiser's rule seems obsolete (Darlington 1997). Therefore for the analysis, the Kaiser rule was used as a start point and the resulting factor structure was analyzed using logical reasoning which helped to understand if the grouping of questions made sense from a qualitative stand-point and also from a past literature perspective. A 7 and 6-factor structure was also tested, as a part of the factor reduction procedure for factor analysis, which when analyzed gave similar results. These factor structures had reduced explanation of variance compared to the 8-factor and still could not provide a logical grouping of the variables. Finally, a 5-factor structure was run and analyzed. The following conditions were used to run the factor analysis in SPSS 18 (similar in the other cases) the following were selected as options within factor analysis; extraction method – principal components, Number of factors to be extracted-5, Missing values- delete pairwise, sort loadings and suppress loadings below 0.4. The initial iterations for the 5 factor structure show that the total variance explained by the 5 factors is about 57%. This value is acceptable for exploratory factor analysis. Values below 50% are considered low and unacceptable (Liau, Tan and Khoo 2011).

The rotated component matrix based on a Varimax rotation for 5 factors gives us a matrix with 5 factors, it was realized that that this question alone is a standalone question which respondents could have considered irrespective of 5 principles of Womack and Jones. This question was thus deleted. Questions with loadings below 0.4 were deleted. All loadings below 0.4 were suppressed and therefore show a ‘blank’ for that variable.

Cross loadings are highlighted which are minimal in number and acceptable in Exploratory factor analysis. It is difficult to get a factor structure without any cross loadings in exploratory research. A Varimax rotation was used in this case for rotations of loadings. McIver and Carmines (1981) say, “It is very unlikely that a single item can fully represent a complex theoretical concept or any specific attribute for that matter" (p. 15). They go on to say, "The most fundamental problem with single item measures is not merely that they tend to be less valid, less accurate, and less reliable than their multi-item equivalents, it is rather that the social scientist rarely has sufficient information to estimate their measurement properties. Thus their degree of validity, accuracy, and reliability is often unknowable".

In order to do this, the measurement model is composed of latent variables and manifest variables. Latent variables represent a theoretical construct that is not directly measurable. In order to examine phenomena involving latent variables, a researcher must operationally define the latent variable in terms of the observable characteristics the latent variable is believed to have or the behavior it is believed to represent. Manifest variables are observed (i.e. directly measured) indicators which represent the latent variable.

The notation used here for manifest variables is as follows; "Cij", where 'i' range from 1-5 and 'j' range from 1-7. For example, the number notation 'C12' means Category 1, manifest variable 2(within that category), similarly, 'C33' would mean Category 3, manifest variable 3 (within that category) and so on. There are the 5 categories/ principles/ latent 1st order variables present in the model, the principles being the 5 principles of Womack and Jones (Shetty et.al. 2011).

Based on the 5-factor structure after removal of variables 'C13' and 'C57', the new structure is as shown in Table 4.1. The new factor structure explains a total variance of ~ 60% for the data for this model. There are 27 questions/variables in this new structure.

Looking at the output for rotation of loadings using the Varimax method, the improved 5-factor structure has 4 cross-loadings for 4 different variables can be seen in Table 4.2. The underlined bolded number shows the cross-loadings in the model. This factor structure is now analyzed for qualitative grouping. There seems to be a sensible grouping structure based on some qualitative characteristics. This structure is a simpler structure, than 27 variables/ questions, and explains an underlying 5-factor structure having at least 3 variables or more within each component/category. Having less than 3 variables per category is discouraged as it does not produce enough detail to a category and also sufficient difference among them. The rotated structure has 10, 5, 5, 4 and 3 variables/ questions forming components 1,2,3,4 and 5 respectively. A Varimax rotation helps in achieving a clear loading structure that can be studied qualitatively. The qualitative analysis can be explained for the groupings of variables as follows;

A qualitative review of these questions showed a common theme of "Value Flow", meaning that a smooth and continuous flow of product through the entire system is important for successful Lean implementation at the workplace from the eyes of the employee. To accomplish this, minimal batch sizes and inventory of all types and Just in Time systems including Kanban- type product flow are some of the important characteristics. The third grouping could be termed as "Tools and Techniques", meaning the so called tangibles tools of Lean that can be used to train and coach the employees in order for them to identify and remove waste. Tools like value stream mapping, 5S and root cause analysis, etc. can be used for this purpose. These tools can be applied at all levels of the organization to help train and put all employees on a 'level ground' when Lean implementation is done. The fourth category has a common theme made up of standardization, procedures, detail to follow schedules based on demand and implement corrective actions in timely manner. This could be termed as "Discipline". The fifth category addresses the customer requirements and how it can be converted to work requirements, clear communication at all levels and essential feedback from customer provided to organization to make improvements. This category could be termed as "Voice of the Customer", a voice that always has to be heard and kept at the center of every improvement process, in order to not only provide focus but also direction.

Table 4.1: Total Variance explained after deletion of 2 variables

Total Variance Explained

Component		Initial Eigenvalues			Rotation Sums of Squared Loadings		
		Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
dimension0	1	10.105	37.427	37.427	4.766	17.654	17.654
	2	1.841	6.818	44.245	3.521	13.039	30.693
	3	1.618	5.992	50.237	3.109	11.514	42.207
	4	1.359	5.032	55.269	2.667	9.878	52.084
	5	1.225	4.537	59.806	2.085	7.722	59.806
	6	1.094	4.052	63.858			
	7	1.035	3.834	67.692			
	8	.897	3.324	71.016			
	9	.784	2.903	73.919			
	10	.778	2.880	76.799			
	11	.709	2.627	79.426			
	12	.660	2.443	81.870			
	13	.574	2.127	83.997			
	14	.530	1.964	85.961			
	15	.454	1.681	87.642			
	16	.441	1.633	89.274			
	17	.419	1.553	90.827			
	18	.367	1.359	92.186			
	19	.356	1.320	93.506			
	20	.292	1.083	94.589			
	21	.266	.984	95.573			
	22	.245	.906	96.479			
	23	.239	.887	97.366			
	24	.225	.831	98.197			
	25	.201	.744	98.941			
	26	.167	.619	99.560			
	27	.119	.440	100.000			

Extraction Method: Principal Component Analysis.

Table 4.2: Varimax Component Rotation matrix

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
C51	.789				
C52	.693				
C32	.680				
C55	.636				
C12	.630				
C53	.586				
C11	.574				
C56	.543				
C24	.492				
C54	.466			**.421**	
C43		.766			
C34		.712			
C45		.701			
C33		.634			
C44		.621			
C23			.779		
C25			.655		
C35		**.433**	.633		
C31			.531		**.436**
C22			.504		
C42				.776	
C41				.628	
C14				.615	
C21	**.416**			.483	
C16					.719
C17					.706
C15					.650

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 9 iterations.

Finally the factor analysis showed that there was some difference between the groupings of questions based on the literature and the groupings based on practitioners'' responses. In theory, the two models would be in agreement; however, this is not always the case in exploratory research. Differences between the two models appear to indicate that the way practitioners perceive Lean and the traditional way of presenting and training individuals on Lean principles may be different.

5. Conclusions

In conclusion, the goal of this research was to look at a stepwise method to reduce a factor structure in EFA to a logical set of factors that could be backed by Literature and analytically.

Based on the research outline, the proposed model was created based on the Womack and Jones' model of 5 Lean principles. Questions were developed and validated used a mixed methods approach. The recommendation based on the results was a 5 factor structure comprising of 27 questions. The recommended factors were; Culture of Continuous Improvement, Value Flow, Tools and Techniques, Discipline and Voice of the Customer.

This new improved 5-factor model was the result of conducting factor analysis using the data sample of 118 responses. These factors have significance and relevance to what is seen in the Gemba in present times.

If this structure is analyzed closely, it is noticed that it has some similarities to the 5 principles of Womack and Jones. The new model seems to be a restructured Womack and Jones model. Restructured meaning, the questions have moved/ rearranged to form groupings that may be similar to the Womack Jones model at the same time provide a better fit to the responses from practitioners. The first category of 'culture of continuous improvement' formed resembles the 'pursue perfection' principle, the second category 'value flow' resemble the mix of the principles 'make value flow' and 'pull value', the third category of 'tools and techniques' resembles the principle of 'identify a value stream' and the fifth category of 'voice of the customer' is similar to the principle 'define value'. The fourth category of 'discipline' is similar to the 'pull value principle'. Thus we realize and conclude that the Womack and Jones model indeed still plays an important role in Lean assessment today. One conclusion that could be drawn from these results is that, while the Womack Jones model might be extremely easy to train and imbibe Lean principles in the workplace there may be a slightly different model by which employees perceive this implementation.

These similarities are not coincidental. Literature has led us to believe that there was no consensus regarding the principles or factors that define Lean. Even though Womack and Jones' 5-Lean principles is a widely accepted model of representing Lean thinking there are various other factors that play an important role in Lean implementation today. The 5 factors of the proposed model do seem to have some mention in Literature and could thus further support the claim that this model is indeed the new approach to assessing Lean implementation from an employee perspective.

Literature has mentioned that although employee practices were found in sustaining Lean (Womack and Jones (1996), we notice a lack of pronounced person focus in the five Lean principles. This might be misleading because individuals are an essential part of a lean culture according to Liker (2004), Veech (2004) and Mann (2005); hence, cultural aspects should be found in every attempt to approach Lean in a business. This supports the emergence of the factor, 'Culture of Continuous Improvement'. By utilizing Lean tools and techniques, the waste can be reduced to a desirable level. Lean strategy brings a set of proven tools and techniques to reduce cycle times, inventories, set up times, equipment downtime, scrap, rework and other wastes of the hidden factory (Anthony, Escamilla and Caine 2003). This lends support to the formation of the factor, 'Tools and Techniques' in the proposed model. Nightingale (2009) mentioned that ensuring stability and flow are foundational to any enterprise transformation effort. Lean works to eliminate those places where value adding work on material or information is interrupted (Howell and Ballard 1998). This further supports the importance of the factor, 'Value flow' in the proposed model. In the book Lean Thinking, Womack and Jones, mention about the German mindset and how that hindered in their problems of change and improvement. They mention that the Germans need to stop prioritizing the engineer's definition of value, "voice of the engineer," over the customer's definition of value, "voice of the customer." Womack and Jones believe that this customer mindset is very important in Lean thinking (Womack and Jones 1996). This validates that the factor, 'Voice of the Customer' as an important factor in the newly proposed model. Companies that bypass the discipline phase will be unable to sustain achieved results and may in fact undermine any attempt to implement a Lean manufacturing system (Harbour 2002). This validates the emergence of the 'Discipline' factor in the proposed model which is required for sustaining a Lean environment and culture.

Thus all factors of the proposed model have some background in history and Lean literature leading us to believe that this model may indeed be a new approach to understand and teach Lean. This supports the initial idea of the research that Lean principles have evolved and have changed over time to have a more holistic perspective based on employee perception. The new categories can help evaluate how people perceive Lean implementation effectively and if there is one or more categories that score low, emphasis could be given in training those categories. This makes the training more focused and purposeful.

Thus by using EFA in a methodical and logical framework one can arrive at good results and subsequent conclusions based on prior literature and research in the field.

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An Innovation of the 21st Century in Social Networking

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Abstract

There are many different sites that connect users all over the world with the click of a button. However, there is one that has created a phenomenon - Facebook! The demand for web 2.0 technology is growing rapidly. Without a doubt, Facebook is the key element in the new Internet era. Facebook has swept the culture and become an integrated part of all walks of life. With its young CEO and free spirited business culture, Facebook represents a new generation. Facebook becomes a phenomenon.

This paper reviews the company's growing path and the ways the website has changed society. Also, its critical success factors will be identified.

1. Organization Background

Facebook, a company that started in a college dorm, is now the most widely used social network in the world. The website provides people with an easy and convenient way to stay in touch with other people around the globe and businesses with a free efficient way to advertise and quantify fans. Few people would believe that the billion dollar company began just a few years ago in a college dorm room, but that is exactly how it happened. In February 2004, four Harvard University students, Mark Zuckerberg, Dustin Moskovitz, Chris Hughes, and Eduardo Saverin created and launched what they called thefacebook.com. The website was originally designed as a networking site exclusively for Harvard students, a social network tool for students to interact and connect via an online profile. And it was an instant success. A month later Facebook had expanded to support students from three more Ivy League universities. In August that year, Zuckerberg and Moskovitz dropped out of Harvard to focus on their fast growing business, and by December 2004 Facebook had reached 1 million users [3][14].

Over the next year Facebook continued to develop their brand and expand on their services. Facebook had grown up to support hundreds of college networks and eventually high school and international networks. This opened doors to many users, but increased the pressure on online privacy issue at the same time. Facebook was forced to adapt to the needs of its users and increase privacy settings. Privacy to this day continues to be one of Facebook's most difficult challenges. In September 2006, Facebook expanded so that anyone with a valid email address could join. This change opened the doors for iconic marketing enhancements like the "like" button and the share feature. These features enhanced Facebook as a marketing tool. Allowing Facebook to see what its users enjoyed. The launch of Facebook's mobile application in 2008 was another monumental step [4] for the company.

With the growth of smartphones, specifically the IPhone, a Facebook application changed the Facebook experience. Facebook became less of something a user would just occasionally check into but something he or she could check and update constantly throughout the day. Social media sites like Facebook and their competitors in some ways drove the expansion of smartphones. By 2011, 46% of mobile phone owners in the United States owned a smartphone [2]. Facebook is currently the number one free social app on the Google Play store and the number two free social app on the Apple App Store. But with success comes challenges. As Facebook is gaining more power through the information of its users, the issue of privacy has become a major focus. With the fear of government regulation touching down, Facebook acknowledges the changes the company needs to make.

2. Setting the Stage

Facebook offers a variety of virtual products like Timeline, News Feed, Groups, Friend List, and Activity Log, to name a few. Facebook's innovative site has changed the world of communication and essentially shrunk the world [17][23]. People now have the ability to connect, chat, and interact with people half way around the world. Although it did not create online messaging or file uploading technology, Facebook innovated it. Facebook created a venue for people young or old, rich or poor, to interact through pictures and updates. With mobile integration and the rise of smartphones and tablets, Facebook has been able to stay ahead of the curve and adapt its site to the new Internet access mediums. Facebook works closely with various device manufacturers, like Samsung, to integrate it into the operating systems of the device, easing access for users. Facebook also uses its connection feature with third party mobile applications, giving users the ability to compete and share application experiences with their Facebook friends [13].

Facebook embraces the fact that its empire to be built not by professional web site programmers, or a technology company, but college students using open source software. Facebook encourages creativity and requires it of all 3000 of its employees [25][26]. Facebook refers to its philosophy as hacker culture. Facebook describes it as "an environment that rewards creative problem solving and rapid decision making". Zuckerberg has created an environment for his employees and continues to strive for more; he has created what the company calls Hackathons, an internal event that features the company's engineers working up to 12 hours straight on prototype projects. This event not only encourages creativity, but has also produced some of the site's most successful features like Timeline and Chat. The open and free culture that Zuckerberg created for his company has made it incredibly successful up to date. But with recent acquisitions from Instagram and privacy issues in the daily news, the future of the site is always in question. After all, MySpace was the leading social network website until the rise of Facebook. Facebook was able to buyout its most recent competitor Instagram, but new applications are created regularly, and only time will tell whether Facebook is able to maintain its throne [28][32].

3. Case Description

There are many ways Facebook can be used for besides photo uploading and chatting. Some employers do advertisement on Facebook, while others upload games like Farmville. But apparently, Facebook has been revolutionary with its use of certain technologies available to users on its website. Some have been scandalous, such as *facial recognition* [8], but others have come to be a part of the virtual society of social media.

As forth-mentioned, Facebook began as an experiment by a couple of college students. With membership expanding, no revenue coming in, and all of the acquisition bids to take over Facebook, it was a tough challenge for Zuckerberg to maintain the company. Parker, then President and founder of Napster, was able to help him and the company to find investors. Soon afterwards, the company took a couple of tough blows, such as a lawsuit and the forced resignation of the company's first president, Parker, who was arrested due to the possession of cocaine. However, Zackerberg was able to manage and go through the tough times.

Another issue that came up when the company decided to expand Facebook further in its early days was the extending of membership to high school students and internationally. There were concerns about the intertwining of a social network between people above and below the age of eighteen. Facebook overcame this issue by participating with organizations such as Wired Safety [12]. Facebook was able to advance further technologically when someone submitted a market place app to its website, which, at the same time, encouraged other people to submit their own apps for use over the website. Shortly after the acquisition of Para Key, Facebook introduced its mobile device platform. This platform was a revolution for social media and a step further, too, for the ongoing success of Facebook.

With huge expansion of the product, better management was required due to the lack of organization [10]. More board members were put in place, and a COO, Sandberg, was hired. This change initially split the company into two main sections between Zuckerberg who handled the website directly and Sandberg who managed finances.

Onwards with its continuous expanding, Facebook's financing for servers was still an issue. Making a deal with Triple Point Capital was a move that helped Facebook in avoiding a loss in equity and funded the purchase of fifty thousand servers along with an upgrade of the company's infrastructure. Soon after Facebook set up its first datacenter, while still occupying space in three other places, the datacenter was moved to Oregon in a response to the continued growth of users.

In 2009, Facebook set up the "like" feature and was becoming the largest photo sharing center on the Internet. The expansion required the company to attain more equipment for a large technological storage. Building such a huge storage was costly, and Facebook was starting to look for further ways to expand the monetization of its product. Eventually Facebook's credits came into play [29]. Facebook continued to acquire companies, which further added technological advancements to its product, such as check-ins, and moved its main headquarters to Menlo Park, California [6]. The company also dealt with more privacy backlash, which eventually ended with a settlement of the Federal Trade Commission.

Opportunities arose as well. With the increased technological use of smart phones (Zheng & Ni, 2006) and the easily accessible Facebook mobile platform, a plenty of continued monetary growing potential was given to the corporation along with a potential expansion to China and a better relationship, from what was truly a historically rocky relationship, with the US government. Evidently, Facebook has been handling arising challenges efficiently. Next, some of the internal and external factors that aided Facebook to its success will be explored.

4. External Factors

4.1. Socio-Cultural Factor

It is human nature wanting to belong to part of a group or reveal one's own individuality. People all strive to become part of movements and are interested in making friends and socializing [7]. Facebook gives the world a second society where people can do the same without leaving their homes, or by showing pictures of recent activities to share with everyone connected.

Facebook's product is something that is appealing in human nature because it allows people to be connected in a manner of seeing someone and being able to become part of the same network over the Internet.

The socio-cultural factor is actually so important to Facebook that it is known to hire recent college graduates in their twenties because of the importance of moving with the times [10][31]. Without the human desire wanting to be connected with others, even in a virtual method, Facebook cannot have been successful. This factor is what draws people into Facebook and keeps them there.

4.2. Competitive Factor

Facebook is not the first social media website occurred on the Web, but it did bring up new ideas that its competitors did not have yet. When Facebook was created it was first designed to connect friends and be different from the blog-like product offered by MySpace.

It did not clutter users with advertisements, an important concept that led to the instant popularity of the website [15].

Facebook keeps an eye out for all its possible competitors, since it is one of the biggest threats posed against the company. As a result, the company has acquired a variety of companies ranging from Para Key to Hot Potato and utilized them within Facebook itself to improve its own website. In reality, factors within Facebook that contribute to making it so unique most of times have come from the acquisition of possible competitors. For example, Facebook mobile and check-ins both came from acquisitions.

4.3. Technological Factor

Throughout recent years it has been quite noticeable how the traditional marketplace has been substantially changing. Companies, such as Blockbuster, are going out of business due to the seemingly endless expansion of e-commerce over the Internet. People are changing the way they have traditionally lived and have been more subjected to spending their hours over the Web, instead of perhaps travelling to a physical store to buy something. This technological revolution that is quickly unfolding is a huge factor in what allowed Facebook to become a success, because it also continued to contribute to technological advancements [18].

Facebook allows people to socially connect with others over the Internet while offering them options to use apps, post up photos, and status updates, etc. Other than Facebook's contributions to the social media market, Mark Zuckerberg established Facebook at an essential moment. The company emerged in a moment when people were becoming more accepting of new ideas, such as cell phones. People had already started steady use of the Internet in a consistent basis, for instance, in doing research for a project, downloading songs, or even using MySpace. Facebook personalized and made its website seem more exclusive towards friends, and slightly less like a blog, which MySpace resembled [1]. Thus, Facebook has engraved itself into the new technologically obsessed culture that defines our decade [19][27].

5. Internal Factors of Facebook

5.1. Team Orientation

A variety of small teams with three members per group, consisting of mostly recent college graduates in their twenties, is what Facebook runs by. This prodigy is a huge factor in what makes Facebook so unique. In order to keep employees challenged, teams are switched up around every year and a half.

For Facebook, it is crucial to stay on top and perpetually introduce new and innovative ideas to incorporate. The social media market faces a huge amount of competition, especially with the increasing popularity of e-commerce. Facebook needs to keep users entertained. With fresh products being offered and change in format every once in a while, Facebook has to be able to maintain a competitive advantage.

Mark Zuckerberg also makes sure that teams within the company are constantly occupied. He sends each team five tasks to complete per day, and encourages employees to work fast and to break expectations [10].

5.2. Tolerate Failure (or Constant Innovation)

The initial idea of Facebook is to be innovative, and this aspect is continuously playing a role in the company's culture. Facebook looks to break barriers by being the first to introduce new ideas, apps, etc. to the social media market. Throughout the company's history risks have been taken repeatedly, such as the introduction to timeline or when the "like" button was introduced, etc. In fact, the CIO of Facebook stated, "One of the things that are really powerful is a license to fail. When you're willing to tolerate failure, people are willing to do things differently. And if you're not willing to do things differently, you have to do it in a tried-and-true way, which is not innovative" [9]. These risky innovations have allowed Facebook to flourish.

Facebook has turned down every acquisition bid, and all of these actions have been a huge risk in itself, especially since the company started with no monetization policies in order to expand. Facebook has introduced some new innovative ideas such as the "Facebook Platform" which created a virtual market place for programmers and developers to submit their apps through the website. Other innovative ideas that have been introduced by Facebook include the tagging of people in multi-medias, poking others, etc. Constant innovation is what has been driving Facebook to success [21].

5.3. User Preferences (or Attention to Detail)

Facebook from the start has always been about user experience, which is substantially something that has driven this company to such an enormous level of success. In order to incessantly attain the best user experience possible, investments in research and development and software engineering are crucial areas where Facebook puts a lot of money into [22].

Facebook places a large focus on user feedback about new prototypes, apps, and the like. Yet development from research is actually a long term process due to the slow and steady progress of enhancing quickly released prototypes. Therefore, much attention must be paid to details. Facebook has made this approach a major part of its organizational culture, which was a crucial move due to its product which depends on keeping and attaining users. Hence, knowing user preferences and continuously incorporating those preferences is a huge factor in Facebook's success.

Facebook is also a great place for businesses to conduct consumer relationship management. Customers who are unsatisfied with a product can find that product on Facebook and write directly to the manufacturer in minutes. Others who share the same feelings can join in on the conversation. The feature is a win-win situation. Some consumers can get their concerns heard right away and others can join in to follow up. Subsequently, manufacturers can receive the information and correct their findings right away. Facebook has become a communication solution. This type of speedy communication is something corporations had been struggling with for years. The need for such a service has existed for a long time [24].

6. Current Challenges/Problems Facing the Organization

Facebook has to face a lot of challenges with regard towards the continued success of the company. Constantly progressing forward and hiring new talents drive the company to continue to be on top of the social media market. Facebook shares were offered in May 2012 at \$38, but after an opening hour's jump, it slid over the next two weeks to as low as \$25.52 on June 6. Thereafter, its stock has risen more than 20 percent, closed at \$31.09 on June 29. Facebook and its underwriters have been criticized for being too aggressive on the size and price of the offering. Still, many experts argue that it is impossible to discount the psychological impact of Nasdaq's problems. Analysts' views are mixed, but investors now seem to be focused on the potential for growth of the world's largest social network.

Although Mark Zuckerberg has been the main force driving Facebook to its current level of prosperity, his management structure goes against everything a potential investor wants and expects from a one hundred billion dollar corporation, a predictable hierarchical structure. Facebook is managed in essentially two parts. Zuckerberg is in charge of the product part of Facebook that looks to further increase the number of users and their level of engagement on the website. The other part is the finances and money making section, which is managed by COO Sheryl Sandberg [5].

Zuckerberg depends on teams consisting of a product manager, part-time engineer, and designer. He gives his small teams six emails per day of what he wants to be done, and after a year and a half he switches his teams up [10]. The reason that this routine is an issue to potential investors is because Zuckerberg always has the last word. Zuckerberg owns an estimated twenty eight percent of the company and has made arrangements with two major investors, DST Global and Accel Partners, which will give him a majority of the company's voting stock [16]. Investors will essentially have no power over board of director choices or any other company decisions because Zuckerberg will be able to single-handedly decide everything.

Facebook needs to face the challenge of properly organizing its management structure in a manner that does not completely depend on the decisions of one man. Facebook is also facing the challenge of skepticism from potential investors. Another challenge that Facebook is currently and will have to continue to face is competitions. Facebook needs to find methods of retaining a stronger appeal to fight the emergence of new and current competitors. User activity decline, which can result from this challenge, can also make potential investors wary and uncertain about the company's growing potential.

However, one of the greatest challenges that Facebook is currently facing is of course privacy issues. Facebook has recently agreed to a Federal Trade Commission settlement that puts it at risk of being fined if there is a violation [20][30].

7. Conclusion

Like much of the World Wide Web, Facebook is a great innovation. It is a virtual experience, but you can have your own identity. It has grown to be so popular in the past few years that it can keep its competitive edge by doing what it has to do to stay on top of the latest social networking sites and just continue using the same approach they have had. It also allows people to communicate and share information in ways that has never been possible. It is an important tool for communication and is growing rapidly.

Since Facebook is one of the greatest innovations of our decade, people appreciate it and use it to their advantage. For example, businesses can create their own pages and advertise and market themselves. An organization may also create its own page and suggest that people like it. You may also look for people who have common interests as you. Can it get any better? It is obvious that Facebook will only expand, but it has to be careful how it will communicate the changes that will eventually be made so that it does not have to deal with the hassle of privacy issues.

Overall, it seems that Facebook has a well-built foundation which maintains its domination in the social media market. There is not much past information that can be used to determine the fate of Facebook other than perhaps MySpace. Facebook seems to be taking the correct approach to handling all the issues that arise to this not entirely familiar market. Facebook has gone from a novel social networking website to a dominant web force that is a staple for businesses to have and families to maintain connections.

It is hard to determine the future of Facebook, as many people would have trouble believing that the current status quo of Facebook would occur then in 2003. But people believe social media has changed the platform of communication forever. It has become a requirement in life. People do spend many of their waking hours on it. Moments of life are documented and shared with the world, and to be reflected on them years later. The problem Facebook will face will be being the face of social expression for years to come.

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Assessing Sustainability of Lean Implementation in Healthcare: A Case Study Using the Lean Sustainability Assessment Framework (LSAF)

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Abstract

In this research activity, an assessment has been made for the level of adopting lean by one of U. S. hospitals in State of Florida using the Lean Sustainability Assessment Framework (LSAF). This framework quantifies the level of lean adoption within the hospital by measuring the agreement level of hospital staff members about the degree of adopting various characteristics of process factors and organizational factors critical for successful lean implementation. Employees' responses were collected electronically by using the Lean Sustainability Assessment Tool (LSAT).

The response rate was 25.5% (total sample size is 55) representing 13 different departments of the analyzed hospital. According to these responses, both process factors score and organizational factors score were calculated for the hospital by using Tastle and Weireman Agreement Measure. These scores represent, respectively, the (x,y) coordinates of the hospital in the Lean Sustainability Assessment Space (LSAS). This space is made of four zones: Making Progress Zone, Commencing Zone, Confounding Zone, and Critical Zone. Hospitals need to be in the Making Progress Zone in order to show a significant level of successful lean implementation.

Collected responses have located the surveyed hospital in the Making Progress Zone with some opportunities of further improvement. However, the observed factors scores of the surveyed hospital departments indicate that characteristics of sustainable lean implementation are variably adopted within these departments. Such variation dictated the need of performing further analysis on individual department level so that department-specific sets of recommendations could be generated.

1. Introduction

By the beginning of the new millennium, many organizations in the healthcare industry started to adopt lean-based tools and concepts in order to improve their levels of performance and achieve higher levels of customer satisfaction. See for instance [1] – [5]. This came as a result of the remarkable positive effect of lean adoption in various firms in the manufacturing sector. However, lean adoption in healthcare organizations has been accompanied with substantial challenges related to proper lean implementation, sustainability of achieved levels of performance, and staff engagement in infinite cycles of continuous improvement towards perfection. In order to mitigate the impact of these challenges during various stages of lean adoption, healthcare organizations' experience with lean needs to be quantified. One of the proposed techniques to attain such quantification is the use of the **Lean Sustainability Assessment Framework (LSAF)**.

This paper shades the light on the level of lean adoption within, hospital A, one of the US hospitals in State of Florida, using the developed framework. This framework quantifies the level of lean adoption within the hospital by measuring the agreement level of hospital staff members about the degree of adopting two sets of critical factors of successful lean implementation. These sets are classified as process factors and organizational factors. In order to accommodate for the observed variation in lean adoption in hospitals, individual hospital departments are considered the "analysis units" of the developed framework. However, the sustainability level of lean implementation of a hospital is obtained by combining various responses of its surveyed departments. A detailed description of the LSAF development stages can be found in [6].

2. Describing the Assessment Process

As shown in Figure 1, the main objective behind developing and implementing sustainable lean-based processes in a healthcare organization is to enhance patient satisfaction through improving the quality of its offered services. Such improvement can be achieved by eliminating process waste and creating continuous flow based on patient's pull, rather than push, mechanism. The success of a hospital in developing and implementing lean-based processes as well as sustaining attained levels of resulting improvements is highly affected by the following two sets of factors:

- **Process factors** (factors that lead to process performance improvement while mastering various lean activities and tools):
    - Process stability
    - Process standardization
    - Patient flow streamlining
    - Mistake proofing
    - Continuous improvement
- **Organizational factors** (factors that lead to enhance the organizational capabilities while developing staff cultural skills required to continuously improve the processes of their organization):
    - Leadership
    - Culture and involvement
    - Respect for employees
    - Change management

Based on these factors, components of the Lean **Sustainability Assessment Tools (LSAT)** of healthcare organizations have been constructed. While a brief description of the assessment tool is presented below, a detailed description of the LSAT development stages can be found in [6] and the tool itself is available upon request.

The LSAT is a balanced tool that evaluates the organizations' level of mastering lean activities and tools as well as the progress in developing lean-based cultural setup. It is made of two sections. These sections are:

- **Section one** which is addressed to quality management staff members to investigate the status of hospital's quality management systems and quality improvement efforts.
- **Section two** which is addressed to all staff members of the hospital and is formed of five main components containing questions written in five-point Likert scale format. These components are:
    - Lean process maturity (LPM),
    - Patient/ specimen pathway integration (PPI),
    - Commitment to safety and Continuous improvement (CSCI)
    - Lean leadership commitment (LLC), and

- Culture and involvement (CUIN).

All factors, except the "change management" one, are covered by these five components. In addition, this section includes a set of a check list form questions about respondent's department, position, and familiarity level with lean activities and tools. For analysis objectives, respondents to this section of the LSAT are categorized as managers, supervisors, and department staff member.

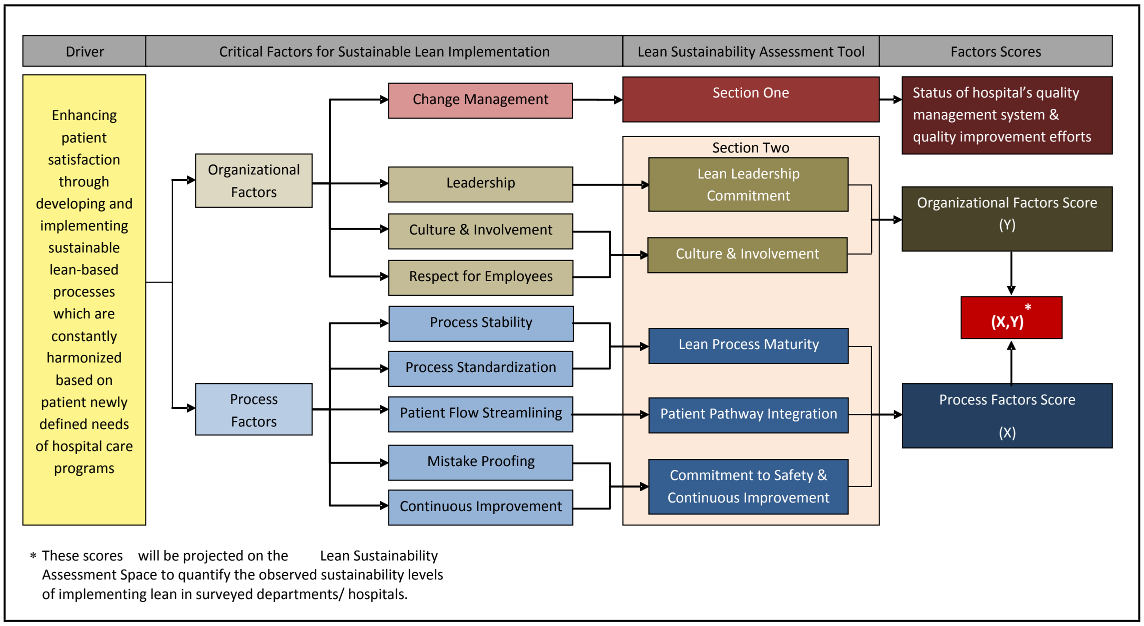


Figure 1. Lean Sustainability Assessment Framework

The sustainability level of implementing lean within a surveyed hospital is determined by data collected by the five survey components representing the major part of this section. The process factors score is obtained by combining responses to the first three components (i.e. LPM, PPI, and CSCI) while the organizational factors score is calculated from combining responses to the last two components (i.e. LLC and CUIN) of the assessment tool. These scores represent, respectively, the coordinates of the surveyed department/ hospital in the two dimensional **Lean Sustainability Assessment Space (LSAS)**. Depending on the values of these two scores of a department/ hospital, the sustainability level of lean implementation in that hospital can be in one of the four zones of the LSAS. As illustrated in Figure 2, these zones are:

- Making progress zone,
- Commencing zone,
- Confounding zone, and
- Critical zone.

The making progress zone is the only zone in which healthcare organizations are considered to have a sustainable level of lean implementation. This is due to the significant enforcement of both process and organizational factors within these organizations. Healthcare organizations in the remaining zones have unsustainable levels of lean implementation with different risk degrees.

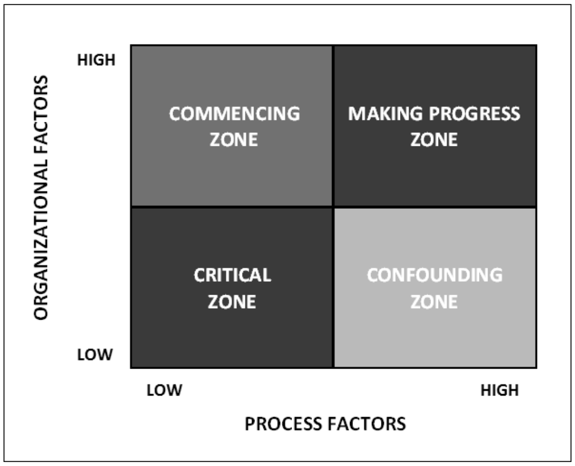


Figure 2. The LSAS

In addition to providing factors' scores to locate a department/ hospital in the LSAS, the LSAT provides the surveyed department/ hospital with information about the level of adopting various characteristics of sustainable lean stated under each survey component of the developed assessment tool. This information is presented in a radar chart format for all survey components as well as the set of questions included under each one of them. Based on this information, current gaps of sustainable lean implementation are identified and a department/ hospital specific recommendations report is developed. This report is presented in a table format containing the desired conditions of various lean characteristics included in the LSAT in addition to their current level of implementation coded in icons format. Implementation of suggested action plan to each surveyed department should follow the priority order inferred from the icons coding in front of each lean characteristic of the recommendations report. A guide for reading the developed charts as well as the recommendations reports is illustrated in Figure 3.

3. Data Collection Setup

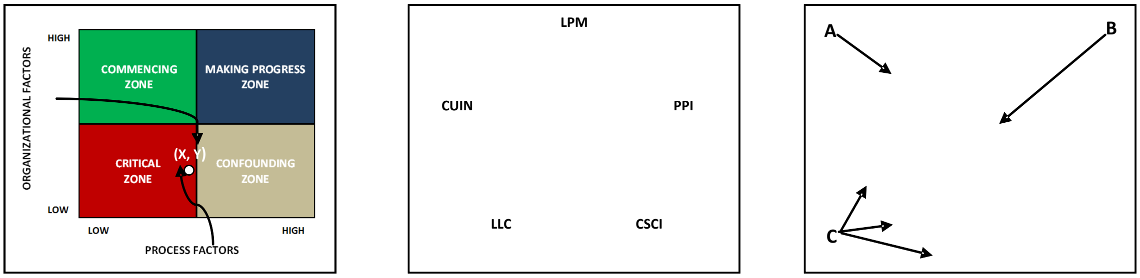
In order to conduct the lean assessment at hospital A using the developed framework, two surveys of section one of the LSAT were sent to members of the hospital's quality management department while 55 surveys of section two of the LSAT were sent to a selected sample of hospital's managers. Both sections of the developed tool were prepared in an interactive PDF format in order to be distributed and returned through e-mail. The data was collected over a two-month period. The response rate to LSAT section one was 100% (total sample size is two) while the response rate to section two was 25.5% (total sample size is 55) representing 13 different departments.
Both departments' code and type are illustrated in Table 1 below.

4. Assessment Findings

According to data collected by section one of the LSAT, hospital A is accredited by the Joint Commission (TJC), "an independent, not-for-profit organization" that accredits U.S. healthcare organizations based on their

Table 1. Hospital A responding departments

Department Code	Department Type
A	Nonclinical Support Services
B	Nonclinical Support Services
C	Clinical Services
D	Nonclinical Support Services
E	Nonclinical Support Services
F	Clinical Services
G	Nonclinical Support Services
H	Nonclinical Support Services
I	Clinical Services
J	Nonclinical Support Services
K	Clinical Services
L	Clinical Services
M	Ancillary Support Services



The LSAS	The LSAT radar chart	The LSAT radar chart of individual survey components
LSAS: Lean sustainability assessment space	**LSAT**: Lean sustainability assessment tool	
Definition: a two dimensional space that quantifies the level of implanting lean in surveyed departments/ hospitals.	**Definition**: a chart that shows the level of implementing each component of the developed assessment tool within surveyed departments/ hospitals.	**Definition**: a chart that presents the level of implementing lean characteristics of each LSAT component together with the level of dispersion observed in the reported levels of implementation.
Range: 0 – 1 for both process factors and organizational factors of sustainable lean implementation.	**Range**: 0 – 1 with a 0.2 increment presented in five pentagons.	**Range**: 0 – 1 with a 0.2 increment presented in five circles.
Surveyed departments/ hospitals are placed in one of the four LSAS zones based on the level of implementing these two sets of factors (X,Y).	**LPM**: Lean process maturity (i.e. how close the current setup of hospital processes is to ideal lean processes.)	**A**: level of implementing lean characteristics in surveyed departments/ hospitals.
Making Progress Zone: both factors are considerably enforced (i.e. X ≥ 0.5 & Y ≥ 0.5).	**PPI**: Patient/ specimen pathway integration (i.e. assessing the efforts of creating continuous flow of patients / specimens.)	**B**: level of dispersion observed in the reported adoption levels of lean characteristics.
Commencing Zone: organizational factors are more enforced than process factors (i.e. X < 0.5 & Y ≥ 0.5).	**CSCI**: Commitment to safety & continuous improvement (i.e. assessing members' attitudes while developing and updating hospital processes.)	**C:** radar chart data points. They vary based on number of questions of each LSAT component.
Confounding Zone: process factors are more enforced than organizational factors (i.e. X ≥ 0.5 & Y < 0.5).	**LLC**: Lean leadership commitment (i.e. assessing the effectiveness of leadership efforts in reaching hospital-wide lean implementation.)	If the level of dispersion (**B**) of the hospital ≤ 0.2, a single hospital's recommendations report needs to be generated.
Critical Zone: both factors are insignificantly enforced (i.e. X < 0.5 & Y < 0.5).	**CUIN**: Culture & involvement (i.e. assessing hospital's cultural setup and members' degree of involvement against lean ideal setups.)	If the level of dispersion (**B**) of the hospital ≥ 0.2, multiple departments' recommendations report need to be generated.

Rating Code	Description	Action Plan Order of Priority
	Agr (SA) ≤ 0.2	1
	0.2 < Agr (SA) ≤ 0.4	2
	0.4 < Agr (SA) ≤ 0.6	3
	0.6 < Agr (SA) ≤ 0.8	4
	Agr (SA) ≥ 0.8	5

Recommendations Report: a report that provides factors' specific recommendations based on current gaps of sustainable lean implementation that have been identified in the generated LSAT radar charts. This report is presented in a table format containing the desired conditions of various lean characteristics included in the LSAT in addition to their current level of implementation coded in colors and icons format. The table, on the left-hand side, shows both color and icon codes and action plan priority orders categorized by various levels of Agreement measures used to construct the related charts.

Figure 3. Charts reading guide

"commitment to meeting certain performance standards" [7], and the ANCC Magnet Recognition Program , one of the American Nursing Credentialing Center (ANCC) programs which "recognizes healthcare organizations that provide the very best in nursing care and professionalism in nursing practice" [8]. The hospital accreditation history by TJC started in 1997 while the ANCC Magnet hospital designation started in 2003.

Hospital A's experience with lean, six sigma, and lean six sigma started in 2002, under what was called rapid improvement process, without any established link between these initiatives adoption and meeting any accreditation requirements. Despite the fact of adopting all the three quality improvement initiatives within various departments of the hospital, positive changes in both quality improvement and cost saving were recognized in hospital offered services due to implementing six sigma and lean six sigma only. The adoption levels of these two initiatives were on department level while they have not yet been considered to be adopted in hospital level. For instance, six sigma and lean six sigma were applied to the following hospital services:

- **Clinical services**: emergency rooms, operating rooms, inpatient units, and outpatient and ambulatory units.
- **Ancillary support Services**: admission and discharge, radiology and imaging,

laboratory services, pharmacy and pharmaceutical services, sterilizing and reprocessing, and patient transportation.
- **Nonclinical support services**: purchasing and supply and information system.

Although hospital A did not implement lean as a management system of the whole hospital, the following approaches, usually adopted by lean organizations during transformation stage, have been observed:

- Recruiting external consultant to guide the organization while applying lean,
- Relying on internal expert(s) to guide the organization through various stages of lean application,
- Providing lean basic training to hospital executives, managers, and supervisors before starting lean application, and
- Starting lean application gradually throughout the organization by first selecting a department or a process where results of lean initiatives can be easily and promptly discerned.

Hospital managers responding to section two of the LSAT showed a considerable variation in their level of awareness about lean activities and tools listed in the assessment tool. This variation is presented in Figure 4 below. Among those lean activities and tools included in the study, waste elimination, continuous improvement, five whys, value stream mapping, types of waste, and five S's were known to 80% or more of the responding managers. However, lean activities and tools like kanban, continuous flow, error proofing, process capability, work standardization, pull, jidoka, and just-in-time were recognized by at least 50% of the managers while at least 20% of them recognized the remaining activities and tools included in the study.

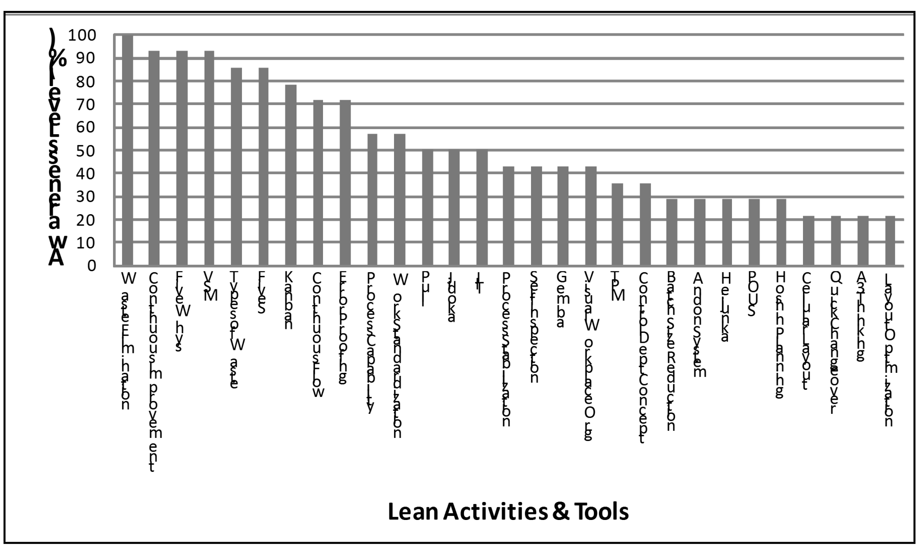


Figure 4. Staff awareness level of lean activities and tools

Now that the hospital's accreditation, level of intervention with lean and other quality improvement initiatives, and level of awareness about various lean activities and tools have been illustrated, the remaining part of this section demonstrates the quantitative investigation about the current level of adopting various characteristics of sustainable lean implementation in hospital A by using the developed framework presented earlier. More information about Tastle and Wierman Agreement and Dissension measures, used as data analysis techniques can be found in [6], [9], and [10].

According to the received responses to section two of the LSAT, the location of hospital A in the LSAS is at the lower left corner of the making progress zone, Figure 5, with 0.58 process factors score and 0.65 organizational factors score. These levels are determined according to the level of responding managers' agreement about the status of adopting lean characteristics that lead to sustainable lean implementation within their hospital.

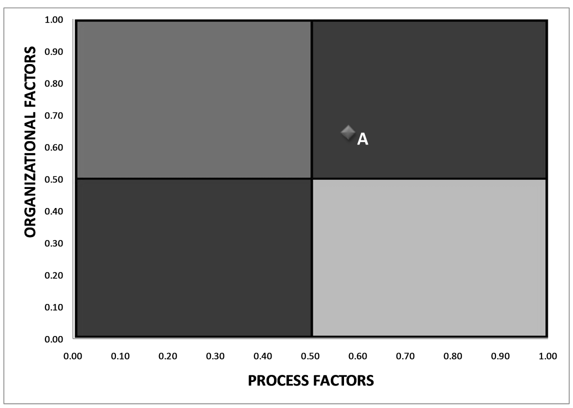


Figure 5. The LSAS of hospital A

Being located within this zone of the LSAS shows the significant commitment hospital A has to progress towards achieving sustainable levels of lean implementation. Nonetheless, as shown in Figures 6 and 7, the hospital has potential opportunities for improvement since some of the essential characteristics of such implementation are less adopted and needs to be reinforced. Figure 6 shows the hospital's adoption status of these characteristics classified by various LSAT components while Figure 7 is a detailed illustration of the adoption status of all lean characteristics stated under each LSAT component (i.e. the outer light gray area). In addition, this figure shows the level of dispersion observed in the reported lean characteristics' levels of adoption throughout the whole hospital (i.e. the inner dark gray area).

From Figure 6, it can be inferred that lean characteristics related to various LSAT components are equally implemented with a nearly 0.6 (or 60%) score.

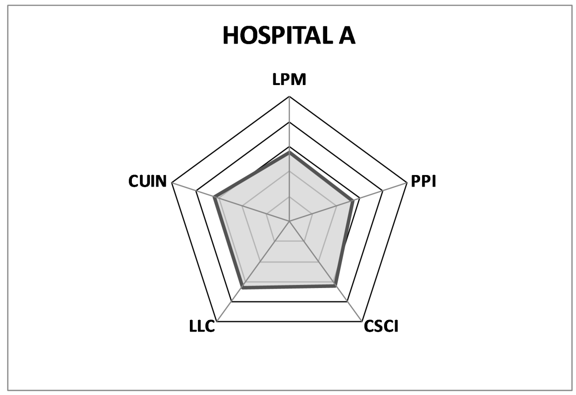


Figure 6. The LSAT radar chart of hospital A

When looking at Figure 7, it can be seen that the level of implementing characteristics related to lean process maturity (LPM) varies from 40% to less than 80% with LPM3, LPM7, LPM10, and LPM14 as the least adopted characteristics and LPM16, and LPM18 as the most adopted ones. These characteristics are:

- **LPM3**: defining both start and end points of all processes within various hospital departments,
- **LPM7**: defining the duration of conducting process steps of all processes within various hospital department,
- **LPM10**: eliminating process frequent interruption due to unplanned equipment maintenance,
- **LPM14**: ensuring the availability of process standards in a simple clear format that visually illustrates desired process performance conditions,

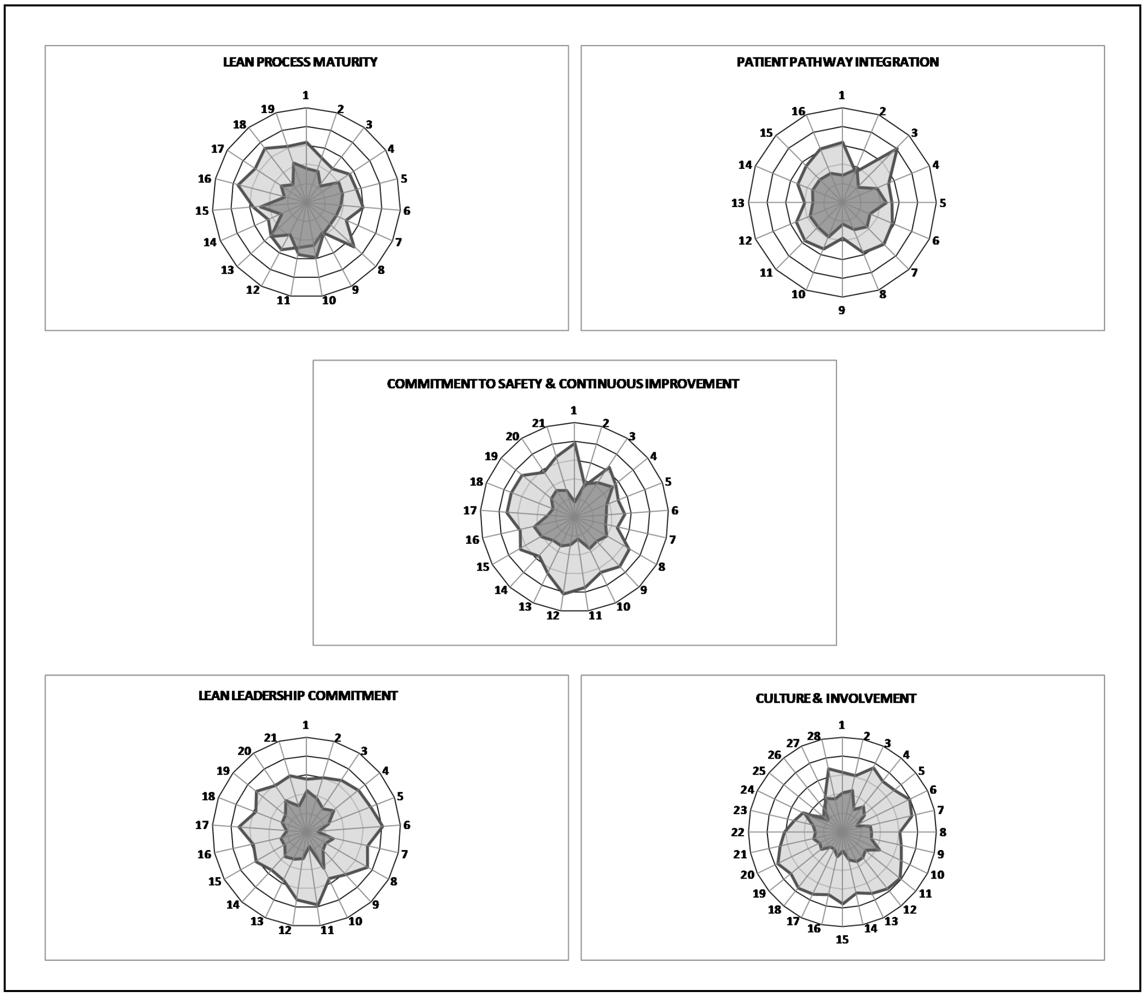


Figure 7. LSAT radar charts of individual survey components of hospital A

- **LPM16**: designing and updating staff trainings based on the standards developed in the hospital/ department, and
- **LPM18**: following a scientific-based improvement methodology (e.g., PDCA: Plan-Do-Check-Act) when changing process standards of various hospital processes.

In addition, Figure 7 shows that lean characteristics related to patient/ specimens pathway integration (PPI) are implemented with a level close to 60 % except for PPI2, PPI9, and PPI13, which do not exceed 40% and PPI3, which reaches 80%. These characteristics are:

- **PPI2**: ensuring the frequent leveling of the department workload to smooth out drastic demand fluctuation in offered healthcare services,
- **PPI9**: synchronizing all consecutive processes in department pathway(s) to eliminate delays in tasks performed on patients/ specimens,
- **PPI13**: synchronizing consecutive patient/ specimen pathways within the hospital to eliminate delays in tasks performed on patients/ specimens, and
- **PPI3**: improving manpower utilization through developing department members' multitasking skills.

Moreover, Figure 7 illustrates an almost 60% level of implementation of lean characteristics of the commitment to safety and continuous improvement (CSCI) LSAT component except for those related to CSCI17, CSCI18, CSCI19, CSCI1 and CSCI12, which range from 75% to 80%, and CSCI2, which does not exceed 40%. These characteristics are:

- **CSCI17**: establishing a clear direct link between all continuous improvement efforts conducted at various hospital departments and the advancement of one or more of the hospital's strategic objectives,
- **CSCI18**: establishing clear definitions about the expected outcomes of all continuous improvement efforts conducted within various hospital departments,
- **CSCI19**: ensuring the availability of expert guidance while conducting all continuous improvement efforts within various hospital departments,
- **CSCI1**: maintaining an adequate level of hospital executives support for conducting continuous improvement initiatives throughout the whole hospital,
- **CSCI12**: having adequate knowledge about the line of support of the department staff in case of having out of control processes, and
- **CSCI2**: establishing hospital executives' daily gemba walk (i.e. walking through patient/ specimen pathway(s) within the whole hospital to identify new areas for improvement),

In regards to those characteristics related to lean leadership commitment (LLC) component of the LSAT, Figure 7 shows a range of adoption levels between 60% and 80% with LLC6, LLC8, LLC11, LLC12, and LLC17 as those characteristics which are highly adopted. These characteristics are:

- **LLC6**: establishing patient-centered hospital strategic objectives with clear goals related to reducing the cost of various hospital processes,
- **LLC8**: establishing patient-centered hospital strategic objectives with clear goals related to advancing the safety level of various hospital processes,
- **LLC11**: establishing measures to reflect, in hospital executive level, the performance of the entire hospital towards achieving hospital strategic objectives,
- **LLC12**: establishing measures, in department management level, to reflect the performance of each department towards achieving hospital strategic objectives, and
- **LLC17**: setting up the right level of urgency to perceive departmental goals and objectives as challenging but achievable.

Likewise, lean characteristics of culture and involvement (CUIN) component of the assessment tool have a level of adoption ranges from 60% to 80% except for CUIN24 (<50%), CUIN27 (around 40%), CUIN26 (30%), and CUIN25 (20%). These characteristics are:

- **CUIN24**: establishing a clear performance-based reward and recognition program to value staff participation in process continuous improvement,
- **CUIN27**: retaining hospital employees by redeploying released staff, due to improving manpower utilization within a process, to other value adding processes in the hospital,
- **CUIN26**: rewarding hospital staff members based on their number of

continuous improvement events attended annually, and

- **CUIN25**: rewarding hospital staff members based on their number of continuous improvement suggestions submitted annually.

So far, the presented analysis provided a quantified view about sustainability of lean implementation in hospital A using the developed framework. It showed both well adopted and least implemented characteristics which are common to all hospital departments. However, recommendations about what to do to move towards higher levels of sustainability should not be made prior to investigating the level of responding managers' agreement about the observed scores of the evaluated factors. Such investigation might reveal the necessity of conducting further analysis on department level and providing department-specific recommendations to each hospital department participating in the assessment process.

By looking at the level of dispersion observed in the reported lean characteristics levels of adoption in hospital A, the inner dark gray areas of Figure 7, a separate analysis needs to be conducted for each department in order to determine department-specific sets of recommendations. This is because the observed level of dispersion is more than 20% (i.e. outside the inner circle of the radar chart) for most of the lean characteristics of the LSAT components. However, before proceeding with the analysis of individual departments of hospital A, the adoption level of lean sustainability characteristics in its various department types will be explored.

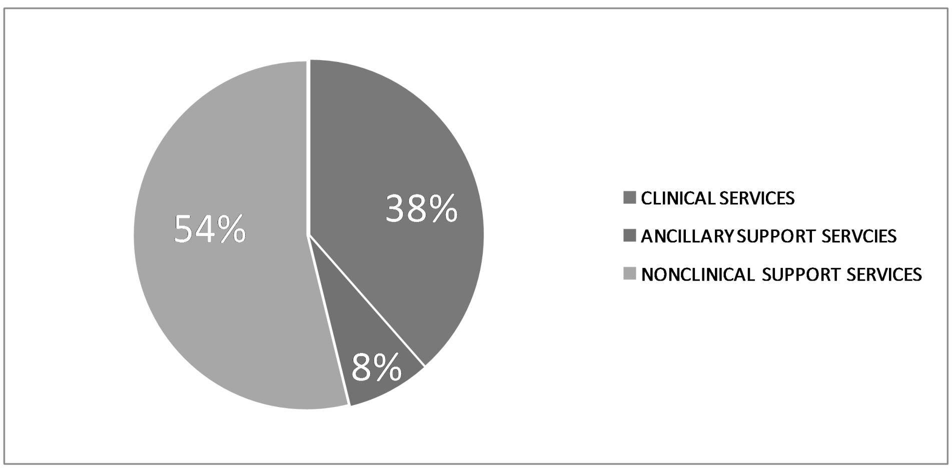


Figure 8. Types of hospital A responding departments

Figure 8 shows that the survey responding departments are classified into:

- Clinical services departments (38%),
- Nonclinical services departments (54%), and
- Ancillary services department (8%).

Factors scores of all these department classes locate them in the making progress zone as presented in Figure 9. However, this figure shows that the level of adopting lean sustainability characteristics in the ancillary services departments supersedes the adoption level of these characteristics in the other two classes. This, also, can be concluded by looking at Figure 10 which presents the LSAT radar chart of department types of hospital A where the ancillary services departments have a near 80% adoption level of all LSAT components compared to around 60% adoption level for the other two classes. In addition, as in Figure 11, the level of dispersion observed in most of the reported lean characteristics levels of adoption within two of the department classes is more than 20% (i.e. outside the inner circle of the radar chart). This confirms the need for performing the analysis on individual department level prior to provide any recommendations for improvement. Such analysis starts by constructing the LSAS of all surveyed departments based on the calculated factors scores.

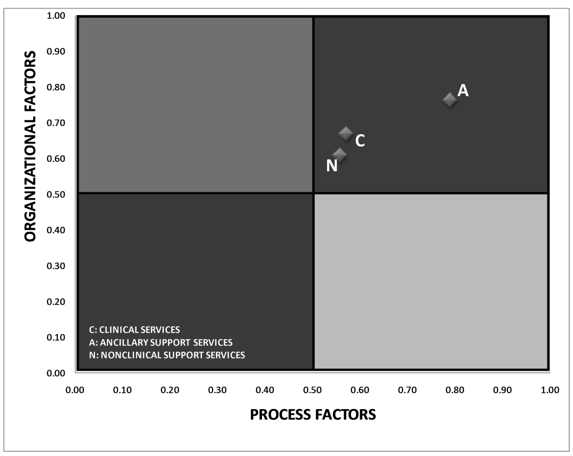


Figure 9. The LSAS of department types of hospital A

According to the factors scores shown in Figure 12, nine of the surveyed hospital departments are located within the making progress zone, three within the commencing zone, and one within the critical zone of the LSAS. Among those departments in the making progress zone, departments M and E have the highest and the lowest observed scores respectively. Other departments in this zone have different combinations of process factors and organizational factors scores between the scores of these two departments. However, the range of variation of both factors scores is nearly identical (i.e. between 0.5 and 0.8).

When comparing those departments which are spread over the commencing zone, it can be seen that department L has the highest level of both factors adoption while departments J and B supersede each other in the level of adopting one of the factors' groups. Figure 12 also shows that department K is located in the critical zone with a nearly 0.4 process factors score and 0.45 organizational factors score.

Another way to analyze the status of implementing these factors within the surveyed departments of hospital A is by comparing their

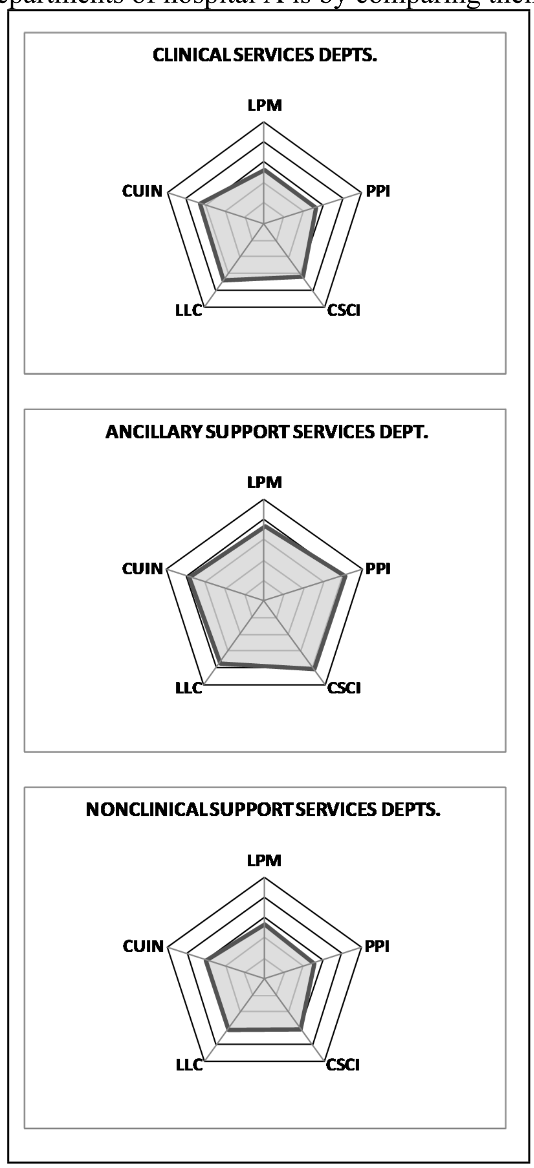


Figure 10. The LSAT radar charts of department types of hospital A

LSAT radar charts which are presented in Figure 13. From these charts, it can be inferred that departments M and K have, respectively, the highest and the lowest levels of factors adoption. In addition, the figure shows the immense deviation of department J in adopting the patient pathway integration (PPI) component of the process factors as compared to other departments. Moreover, the figure shows that departments J, K, L, and B are expected to spend more efforts as well as get more attention from hospital executives in order to achieve such targeted levels of factors adoption as 80% or more. Furthermore, the charts presented in this figure provide valuable benchmarking information about those departments with high adoption levels of some of the components of the developed LSAT. Lean practices within these departments should be analyzed in order to be applied throughout the whole hospital.

A more detailed view about the status of implementing various lean characteristics under each component of the LSAT have been obtained by generating the radar charts of individual survey components of the participating departments. Based on the observed level of adopting these characteristics within the surveyed departments, various sets of department-specific recommendations reports have been generated. These reports are composed of the desired conditions of various lean characteristics included in the LSAT together with their current level of implementation, in both department level and hospital level, coded in icons format presented earlier in Figure 3 as part of the charts reading guide.

5. Analysis and recommendations

As per the illustrated results of the assessment process conducted by using the developed framework, the accreditation history of hospital A reflects the commitment of its members in providing healthcare services with high levels of quality. The nine years of hospital's exposure to six sigma and lean six sigma led to a significantly high level of adoption of the characteristics of sustainable lean implementation. Applying these two quality improvement initiatives on the department level resulted in a recognized cost saving and quality improvement in offered healthcare services. Although hospital A did not implement lean as a management system of the whole hospital, the following approaches, usually adopted by organizations during lean transformation stages, have been observed:

- Recruiting external consultant to guide the organization while applying lean,
- Relying on internal expert(s) to guide the organization through various stages of lean application,
- Providing lean basic training to hospital executives, managers, and supervisors before starting lean application, and
- Starting lean application gradually throughout the organization by first selecting a department or a process where results of lean initiatives can be easily and promptly discerned.

A variation has been observed in received responses to section one of the assessment tool especially when responding to the question about the departments in which lean, six sigma, and lean six sigma have been applied. This variation could be regarded to the different level of involvement each member of the quality management department might have with the conducted projects throughout the hospital.

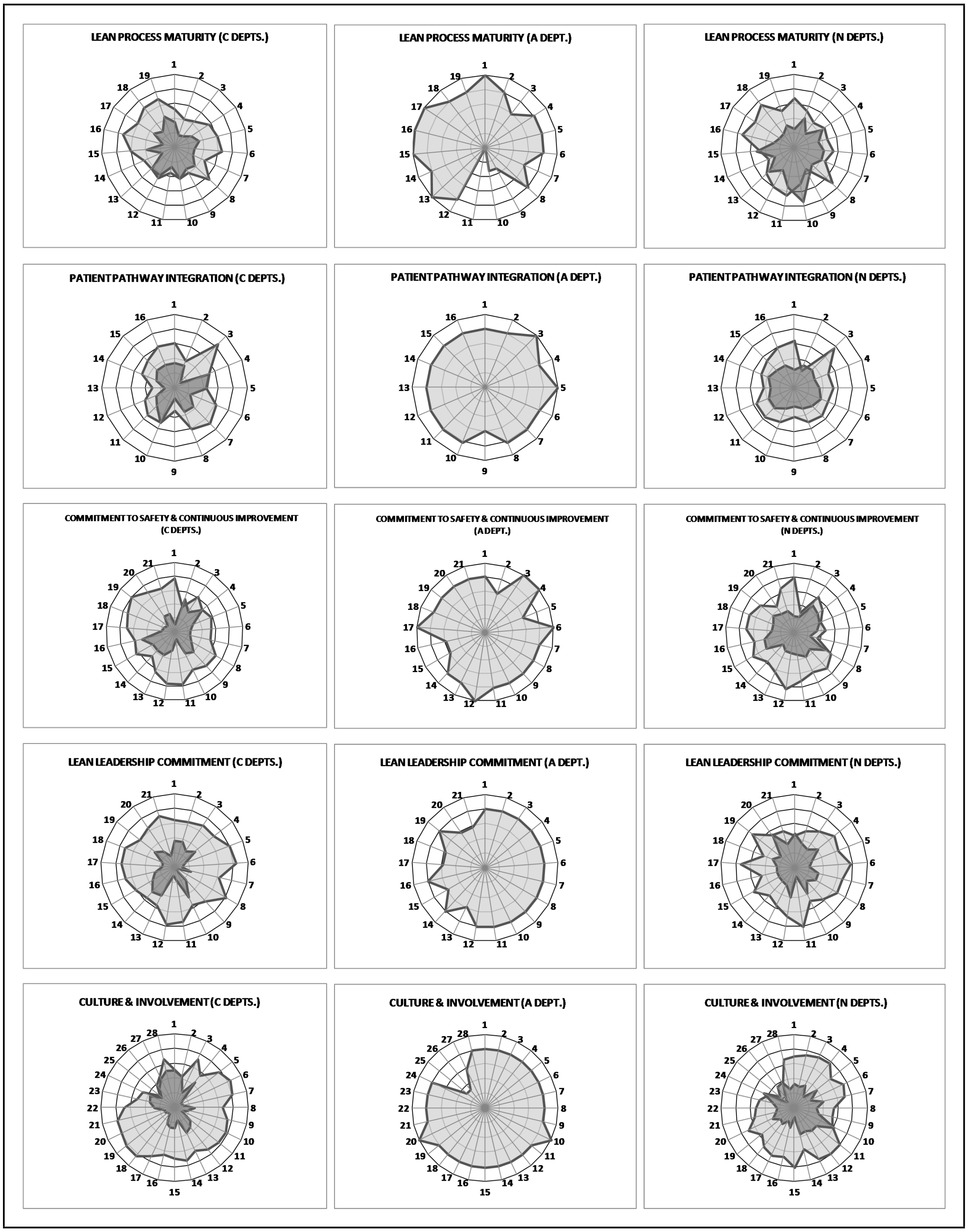


Figure 11. The LSAT radar charts of individual survey components of hospital A department types

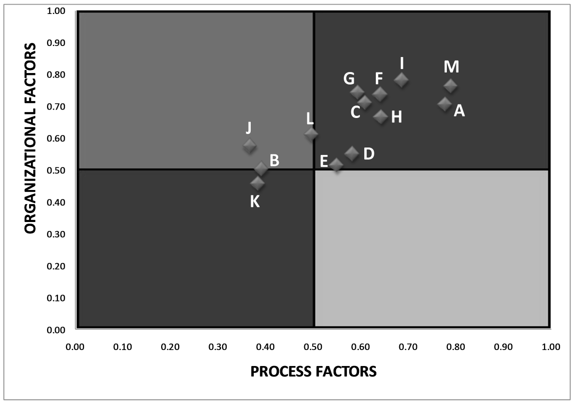


Figure 12. The LSAS of participating departments of hospital A

Due to the fact that the hospital experience with lean is through conducing lean six sigma projects on department level, those lean activities and tools utilized usually in such projects are recognized by 80% or more of the responding managers. These activities and tools are: waste elimination, continuous improvement, five whys, value stream mapping, types of waste, and five S's. However, the remaining 23 lean activities and tools included in the study are known to 20% or more of the responding managers. Among these activities and tools, kanban, continuous flow, error proofing, process capability, work standardization, pull, jidoka, and just-in-time are recognized by at least 50% of the responding managers.

The observed process factors scores and organizational factors scores indicate that characteristics of sustainable lean implementation are variably adopted within various types of hospital departments. The level of adopting lean sustainability characteristics in the ancillary services departments supersedes the adoption level of these characteristics in both clinical services and nonclinical supports services departments. Based on this and in addition to the observed dispersion levels associated with the reported lean characteristics levels of adoption of the surveyed departments, further analysis ought to be performed on department level in order to generate their specific reports of recommendations. Each one of these reports is composed of the desired conditions of various lean characteristics included in the LSAT together with their current level of implementation, in both department level and hospital levels, coded in icons format presented earlier in Figure 3. Hospital A assessed departments should use these recommendations reports in order to move towards enhanced levels of sustainable lean implementation.

Despite the fact that not all departments of hospital A have participated in the assessment process, the obtained results of this assessment can serve as a base for developing hospital-wide action plans to improve the overall sustainability level of lean implementation within the hospital. Table 2 presents a summarized overview about the conducted assessment of all hospital A surveyed departments. It compares the level of adopting each lean characteristic and each LSAT component in various hospital departments with the related factors' score of the whole hospital. For instance, the level of adopting lean characteristics stated under LPM, PPI, and CSCI components of the LSAT is compared with hospital A process factors score while the level of adopting those characteristics stated under LLC and CUIN components is compared with hospital A organizational factors score. Based on this comparison, the percentage of those departments with lean characteristics adoption levels less than hospital A related factors score is obtained for each characteristic stated under each LSAT component. Results of this comparison should be used in developing the action items which need to be performed by all departments of hospital A to achieve higher levels of sustainability of lean implementation. However, hospital executives need to determine the cut-off point which identifies these items so that they are challenging though achievable. This cut-off point is determined according to the following:

- The targeted factors scores of the hospital, and
- The targeted percentage of hospital departments which must exceed these factors scores.

For illustration, if hospital executives determine that the level of adopting lean characteristics must exceed the obtained factors scores in at least 60% of hospital departments, then all lean characteristics with percentage of departments greater than this value must be in the hospital action items. Assuming that the presented scenario is a reasonable objective for executives of hospital A, the list of the action items which should be considered includes those listed in Table 3.

However, the number of these items can be modified by setting higher factors scores targets and/ or decreasing the number of hospital departments with lean characteristics adoption levels that exceed these targets. Nonetheless, prior to finalizing the action items list, it is highly recommended for hospital A to conduct the lean assessment on a wider range to include as much hospital staff members as possible to guarantee their involvement and reflect their level of commitment towards achieving sustainable levels of lean implementation.

In addition to providing the essential information for defining the action items list, Table 2 presents similar percentages obtained for LSAT components to show which area requires more attention in the future developed action plans. It also provides information about the number of hospital departments participating in the assessment process, the leading department(s) for each LSAT component, and factors scores of hospital A.

It could be argued, however, that the recommendation report should include some information about those lean tools by which surveyed departments/hospitals could achieve the desired conditions of lean characteristics included in the LSAT. This is not done in order enforce the concept stated by Dennis that transforming to lean is a journey towards perfection, and there is more than one "correct" path to reach the final destination [11]. This final destination is formed through asking an essential question at milestone stations of the journey. This question simply is "what is the need?" Thus, the provided recommendations format help healthcare organizations answer this basic question in regards to those characteristics which should exist in a sustainable lean implementation setup. Whether or not they fulfill this need using the tools known currently in the lean toolbox is highly dependent on the way they look at these tools.

Despite the fact that they prove to be powerful in leading to satisfactory levels of performance, the currently known lean activities and tools should be thought of as the best countermeasures, not solutions, known up to date to handle those performance challenges encountered by business firms in many industries. These activities and tools proved to be powerful when applied to healthcare industry too. However, prior to use any of these tools, healthcare practitioners ought to ensure that a specific selected tool is the best for fulfilling their specific defined needs and apply any modifications that might be desired accordingly.

6. Conclusion

The presented analyses showed the LSAF capability in quantifying sustainability of lean implementation in hospitals. Additionally, it illustrated the importance of the information gathered about hospital's accreditation status and quality improvement efforts in explaining the observed levels of adopting lean characteristics within the analyzed hospital.

Moreover, the conducted analysis proved the applicability of the developed framework in assessing the level of adopting characteristics of sustainable lean implementation in hospitals even if lean is not adopted in hospital level. Finally, it can be inferred from the presented analyses that the developed framework has the following expected benefits to the healthcare industry, if properly implemented:

- Providing baseline assessment about the readiness of hospitals for adopting lean in hospital level.
- Demonstrating the leadership commitment to achieving sustainable levels of lean implementation.
- Aligning leadership's lean strategies with staff expectations.
- Developing future action plans to achieve higher levels of performance based on the results of the proposed assessment framework.
- Adjusting future action plans to fit different department needs within the hospital based on variation observed in levels of lean adoption.

Table 2. Executive's summary report

<table>
<tr><th>(% Depts. <0.58)</th><th>LPM Survey Comp. (% Depts. <0.58)</th><th>Question Code</th><th>(% Depts. <0.58)</th><th>PPI Survey Comp. (% Depts. <0.58)</th><th>Question Code</th><th>(% Depts. <0.58)</th><th>CSCI Survey Comp. (% Depts. <0.58)</th><th>Question Code</th><th>(% Depts. <0.65)</th><th>LLC Survey Comp. (% Depts. <0.65)</th><th>Question Code</th><th>(% Depts. <0.65)</th><th>CUIN Survey Comp. (% Depts. <0.65)</th><th>Question Code</th></tr>
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<tr><td>62</td><td>LPM14</td><td>46</td><td>PPI14</td><td>46</td><td>CSCI14</td><td>69</td><td>LLC14</td><td>46</td><td>CUIN14</td></tr>
<tr><td>31</td><td>LPM15</td><td>38</td><td>PPI15</td><td>31</td><td>CSCI15</td><td>62</td><td>LLC15</td><td>23</td><td>CUIN15</td></tr>
<tr><td>8</td><td>LPM16</td><td>23</td><td>PPI16</td><td>38</td><td>CSCI16</td><td>69</td><td>LLC16</td><td>46</td><td>CUIN16</td></tr>
<tr><td>23</td><td>LPM17</td><td rowspan="5">Lean Characteristics Priority Order</td><td>% Depts. ≥ 80</td><td>1</td><td>8</td><td>CSCI17</td><td>46</td><td>LLC17</td><td>31</td><td>CUIN17</td></tr>
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<tr><td>31</td><td>LPM19</td><td>40 ≤ % Depts. < 60</td><td>3</td><td>15</td><td>CSCI19</td><td>46</td><td>LLC19</td><td>38</td><td>CUIN19</td></tr>
<tr><td colspan="2" rowspan="2">Number of Participating Depts.</td><td rowspan="2">13</td><td>20 ≤ % Depts. < 40</td><td>4</td><td>31</td><td>CSCI20</td><td>69</td><td>LLC20</td><td>31</td><td>CUIN20</td></tr>
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<tr><td colspan="5" rowspan="2">Survey Components</td><td colspan="2" rowspan="2">Leading Department(s)</td><td colspan="5" rowspan="2">Factors Scores of Hospital A</td><td>62</td><td>CUIN22</td></tr>
<tr><td>77</td><td>CUIN23</td></tr>
<tr><td colspan="5">LPM: Lean Process Maturity</td><td colspan="2">A, I</td><td colspan="4" rowspan="3">Process Factors Score</td><td rowspan="3">0.58</td><td>62</td><td>CUIN24</td></tr>
<tr><td colspan="5">PPI: Patient/ Specimen Pathway Integration</td><td colspan="2">D, M</td><td>100</td><td>CUIN25</td></tr>
<tr><td colspan="5">CSCI: Commitment to Safety & Continuous Improvement</td><td colspan="2">A, M</td><td>92</td><td>CUIN26</td></tr>
<tr><td colspan="5">LLC: Lean Leadership Commitment</td><td colspan="2">F, G, M</td><td colspan="4" rowspan="2">Organizational Factors Score</td><td rowspan="2">0.65</td><td>85</td><td>CUIN27</td></tr>
<tr><td colspan="5">CUIN: Culture & Involvement</td><td colspan="2">G, I</td><td>46</td><td>CUIN28</td></tr>
</table>

Table 3. Suggested list of hospital A action items

Question Code	Desired Conditions
LPM9	Review staff scheduling for each process in each department to confirm the availability of the minimum number needed to achieve the defined process outcomes.
LPM10	Develop a schedule for conducting maintenance activities on all equipment utilized within each department . Whenever possible, shift some tasks of these activities from the maintenance team to the frontline staff.
LPM11	Review the amount of supplies related to each process in each department and define stock levels suitable to trigger the replenishment process of each item.
LPM14	Provide a visual illustration of process performance conditions by presenting their related instructions in a drawing or picture format.
PPI2	Improve departments' response to drastic demand fluctuation in offered services through frequent adjustment of the workload level of each department.
PPI9	Synchronize all consecutive processes in each department pathway(s) to eliminate delays in tasks performed on patients/ Specimens.
PPI13	Coordinate with other hospital departments to ensure synchronization of patient/ specimen pathway(s) throughout the hospital.
CSCI2	Engage hospital executives with a daily walk through different patient/specimen pathways within the whole hospital to identify new areas for improvement.
CSCI7	Establish a feedback mechanism among all consecutive processes in your department to contain errors/ defects prior to have them spread into other hospital departments.
LLC7	Develop patient-centered hospital strategic objectives with clear goals related to reducing both lead and processing time of hospital processes.
LLC9	Develop patient-centered hospital strategic objectives with clear goals related to improving the environmental setup of hospital processes.
LLC10	Develop patient-centered hospital strategic objectives with clear goals related to improving the morale level of hospital staff, patients, and suppliers.
LLC13	Establish a mechanism to measure advancement towards fulfilling hospital strategic objectives on a daily basis.
LLC14	Establish a mechanism that enhances the awareness of all department members about hospital strategic objectives.
LLC15	Ensure that the developed hospital strategic goals are challenging enough to convey the right level of urgency needed to motivate for endless improvement cycles towards perfection.
LLC16	Establish a mechanism to transform hospital strategic objectives into actionable plans for each department in the hospital.
LLC18	Establish a mechanism to transform hospital strategic objectives into specific responsibilities and performance targets for each staff member in the hospital.
LLC20	Establish a mechanism to encourage hospital departments to consider supporting the cross- functional goals of other departments when developing the plan of their own departments.
LLC21	Hospital executives should incorporate plans of all departments into one master plan to assure their alignment towards achieving defined strategic objectives.
CUIN8	Ensure that Lean training sessions are properly structured to progressively improve department members' understanding about various Lean activities and tools and how they can be applied to their daily performed activities.
CUIN22	Ensure that the hospital suggestion program has a mechanism for prioritizing implementation of staff suggestions based on their relevance to hospital strategic objectives.
CUIN23	Ensure that the hospital suggestion program has a mechanism for expediting implementation of staff suggestions, even if they are sub-optimal, based on their relevance to hospital strategic objectives.
CUIN24	Establish a clear performance-based reward and recognition program to value staff participation in process continuous improvement activities conducted in the hospital.
CUIN25	Ensure that department members are rewarded based on the number of continuous improvement suggestions they submit annually.
CUIN26	Ensure that department members are rewarded based on the number of continuous improvement events they attend annually.
CUIN27	Establish a mechanism to ensure that hospital staff members released from a process, due to improving manpower utilization, are redeployed to other value adding processes in the hospital.

- Ensuring employee involvement in the developed action plans and conducted efforts of performance improvement.
- Providing new knowledge sharing channels throughout the whole hospital.
- Applying the framework to more than one hospital can help investigate:
    - The effect of hospital accreditations,
    - The effect of adopting different sets of quality improvement initiatives,
    - The effect of applying lean for different periods of time, and
    - The effect of adopting different approaches while transforming to lean.
- Investigating the differences which might exist among various hospital staff member groups in regards to their perception about level of lean implementation.

7. Future work

Data collected for the study presented in this paper was from one hospital and was provided by one group of hospital staff members (i.e. department managers). Therefore, future studies should include more than one hospital in order to:

- investigate the effect of hospital accreditations on the observed sustainability levels of implementing lean within surveyed hospitals,
- investigate the effect of adopting different sets of quality improvement initiatives on the observed sustainability levels of implementing lean within the analyzed hospitals,
- investigate the effect of applying lean for different periods of time on the observed sustainability levels of implementation within surveyed hospitals, and
- investigate the effect of adopting different approaches while transforming to lean on the observed sustainability levels of implementing lean within the analyzed hospitals.

In addition, future studies should include all staff member of the surveyed hospital to ensure their involvement in both assessment and improvement processes. It will also give the opportunity for exploring the differences which might exist between different groups of hospital staff members (i.e. managers, supervisors and frontline staff) in regards to their perception about the level of lean implementation within the investigated hospital.

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Biomechanical Evaluation of Proximal Humeral Locking Plate with Kryptonite Bone Cement

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Abstract

The purpose of this study is to investigatethe biomechanical effectsof Kryptonite bone cement on proximal humeral locking plate fixation when applied inside cancellous screw holes of trabecular bone. Twenty right arm osteoporotic humeri models were used and fixated with (test group) and without (control group) Kryptonite bone cement. The sawbone models were divided into four test groups (N=5 each) to undergo two separate experiments (Ramp Compression to Failure, and Cyclic CompressionFatigue).

With respect to the control group in the Ramp Compression to Failure test, the Kryptonite group exhibited 9.3% higher mean ultimate load ($p=0.655$), 32.9% higher mean rotational displacement ($p=0.456$), and 37.6% higher mean elastic strength ($p=0.025$).

In the Cyclic Compression Fatigue test, the Kryptonite groupdemonstrated 68.8% higher rotational displacement ($p=0.083$) and 22% higher mean failure cycle ($p=0.564$). For the increasing cycles (increments of 100 from 200 to 700), the Kryptonite group exhibited higher mean rotational stiffness with statistical significance in means above 400 cycles ($p<0.05$).

1. Introduction

In elderly patients, rigid fracture fixation can be difficult due to the weakness of osteopenic or osteoporotic bone [1-2]. The pins, screws, and bone plates often become loose during post-operative physical therapy due to higher levels of wear and tear of osteoporotic bone. This leads to the difficulty of normal callus formation required for proper bone union during the healing phase of fracture fixation. Fractured bones must maintain rigid fixation to mitigate micro motion and minimizefracture gap thickness in order to prevent non-union and allow early mobilization [3]. Since cancellous bone is weaker than cortical bone, proximal regions are even more difficult to stabilize and at higher risk of fixation failures.

In light of complications dealing with osteoporotic bone, many methods have been devised to improve stablebone plate fixation. The use of bone cement is one well-known method to improve thebiomechanical performance of fracture fixation [1-2, 4-5]. The cement compound is injected into the intramedullary cavity to serve as a rigid anchor for cortical or cancellous screws [5]. However, common bone cements have properties of hyperthermic polymerization that may lead to fixation loosening due tobone healing complications [6]. The high temperatures of curing PMMA (Poly Methyl Methacrylate) bone cement can reach dangerous levels that, in many cases, lead to avascular necrosis caused by damage to the bone's blood supply and local soft tissue [5-6].

It is the purpose of this study to evaluate the biomechanical performance of Kryptonite bone cement, aporous biocompatible calcium carbonate compound that is hypothermic in polymerization, comparable in adhesive strength when compared to PMMA, and have more bone-like properties (such as stiffness and porosity) [7].The polymerization of Kryptonite bone cement is at significant lower levels (approximately 110°F) than typical PMMA (which can exceed 200°F)and can reduce the risk of avascular necrosis [7]. Since cancellous bone is weaker than cortical bone, proximal fixation regions may benefit most from cemented aided internal fracture fixation. Thus, proximal humeral locking plate fixation with cancellous screw hole filled Kryptonite bone cement has been chosen in this study.

2. Materials & Methods

2.1. Specimen preparation

Twenty right arm osteoporotic humeri models were divided into four groups (N = 5 per group) for Ramp Compression to Failure Test and Cyclic Compression Fatigue Test. For all specimens, a 1 cm transverse osteotomy was performed atthe proximal surgical neck of the humerus to simulate a comminuted unstable 2-part fracture. The specimens were fixated using a 13.5 cm proximal humeral locking plate, five humeral head cancellous locking screw and four diaphyseal cortical locking screws (Figure 1).

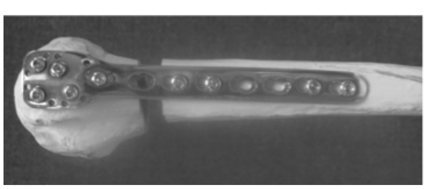

Figure 1. Proximal humeral locking plate fracture fixation (lateral view)

Prior to screw insertion, ten of the specimens (divided into two experimental groups) were supplemented with Kryptonite bone cementby injection into the screw holes of the proximal head plate (interface of trabecular bone attachment) [7]. The models were allowed 24 hours to fully cure prior to mechanical load testing. The remaining ten (divided into two control groups) was not supplemented with bone cement.

Prior to testing, all specimens were inspected for improper alignment of screws and bone plate fixation. A total of 3 Controls and 1 Kryptonite specimen were deemed defective and excluded from testing due to misalignment of bone plate screw insertion that deviated from normal position. Eight of the remaining subjects were divided into the Compression to Failure groups (N=3, Control; N=5, Kryptonite). The remaining eight were divided into the Cyclic Compression Fatigue groups (N=4, Control; N=4, Kryptonite).

2.2. Instrumentation

The tests were conducted with the MTS 858 Mini Bionix II servo-pneumatic materials testing machine. The MTS unit includes a LVDT (linear variable differential transformer) load cell capable to axial forces of ±25kN and axial displacements of ±50mm. A custom torque plate was built to interface with the load cell head that provides constant torque load in the transverse plane (simulating external rotation of the arm). Axial displacement was captured via the MTS force transducer that resides directly below the test specimen of which the entire load transfers. Rotational displacement was captured using a linear variable potentiometer sensor attached to the load cell shaft. Torque was captured using a strain gage sensor that interfaced with the tension applied to the torque plate. Labview software was used for sensor instrumentation interfacing and data acquisition. Matlab, Excel, and SPSS were used for post-data processing, computation, and analysis.

2.3. Test methodology

The humeri models were divided into four groups (2 Control and 2 Kryptonite) for mechanical load testing. Two of the groups (Control and Kryptonite) underwent the Ramp Compression to Failure (RCF) test. The RCF test was used to induce an axialdisplacement of the humeral shaft using a constant axial displacement rate of 2.5mm/min (compression). In addition, an external constant torque of 1.19N was applied counter-clockwise to the humeral head to simulateexternal rotation of the shaft.

The remaining two groups (Control and Kryptonite) underwent the Cyclic Compression Fatigue (CCF) test. The CCF test was used to induce a cyclic axial displacement (sine wave of 1.5Hz with peak-peak displacement of 30mm centered around 15mm) of the humeral shaft. This displacement includes the deformation change of a spring interfaceattached to the distal load cell to allow force absorptionfrom the test specimen and does not represent actual specimen deformation.Like the RCF test, an external constant torque of 1.19N was applied counter-clockwise to the humeral head to simulate external rotation of the shaft.

All testswere executed until catastrophic failure or loss of bone plate fixation. For all specimens, the distal third of the humerus was surgically removed for proper attachment of the distal humeral shaft to the distalbone fixture. The grip provides stable fixation of the distal shaft to prevent translation and rotation in the transverse plane. The head of the humerus was fixated to the proximal bone fixtureto prevent translation while still allowing rotational displacement in the transverse plane.

2.4. Data Reduction & Analysis

Post data reduction and analysis wereperformed to remove irregularities or noise from the data. Matlab was used for computation and plotting of graphs (force-displacement curves). The parameters of interest were then determined by observation of the force-displacement curves. Figure 2 gives the general force-displacement curve for metallic bone plates from ASTM International standard F 382-99 [8].

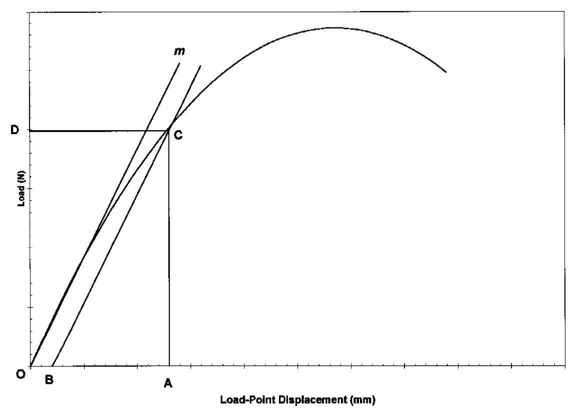

Figure 1. Load-displacement curve [8]

Ultimate load is the maximum axial load the specimen undergoes prior to catastrophic failure. From Figure 2, the peak of the load-displacement curve is the ultimate load point. Ultimate load is measured in newtons.

Axial stiffness is the measure of elastic strength (load to axial deformation) in a material. Stiffness is represented by the slope of m-line in Figure 2 and measured in N/mm. This measure is estimated using the first 7mm (3% strain with original length = 23cm after removal of distal third of the shaft) of displacement of each specimen. The 3% strain is a good approximation of stiffness before yielding since the force-displacement curve is approximately linear up to this region (point c in Figure 2).

Rotational stiffness is defined as the change in rotational displacement with respect to an applied force. In this study, a constant torque of 1.19N was applied counterclockwise to the head of the humerus. With cyclic axial loading, rotational displacement is induced. The cyclic axial load per rotational displacement is used as a measure of rotational stiffness. Figure 3 gives the hysteresis loop for cyclic loading. The slope of the linear portion of the top (loading) curve is used to measure stiffness in N/Deg.

Rotational displacement is a measure of angular displacement of the humeral head when subjected to a constant torque. With ramp or cyclic compression, an angular displacement is induced. The angular position at fracture point is defined as the maximum rotational displacement.

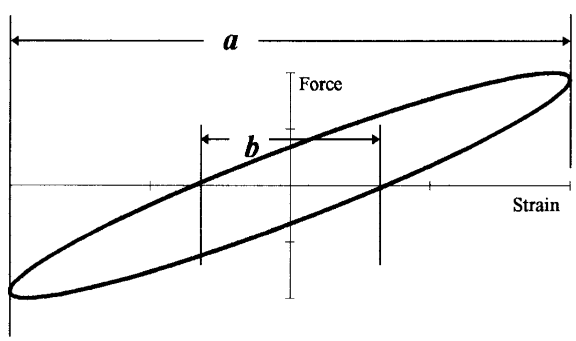

Figure 2. Hysteresis force-strain curve [9]

Number of cycles is the number of periods transpired during a cyclic compressive fatigue test. Number of cycles is synonymous with cycle time and is a measure of fatigue.

These parameters were used in defining and comparing the general mechanical strength of the specimen groups. Due to small sample size and indeterminate distribution, the Kruskall-Wallisnon-parametric test of hypothesis was used to determine statistical significance between mean values of both groups (performed in SPSS software). Statistical significance was determined with an alpha level of 0.05. Since the sample size is small, to recognize the differences in the means that were marginally significant, alpha equal to 0.1 was chosen. The null hypothesis of equal means would be rejected for p-values less than 0.05 and 0.1 and the difference in means will be deemed statistically significant and marginally statistically significant respectively.

3. Results

3.1. Compression to failure

The Kryptonite group exhibited 9.3% higher mean maximum load (Figure 4). The mean difference was not statistically significant (p=0.655). The Kryptonite group also exhibited a 32.9% increase in rotational displacement (Figure 5). The mean difference was not statistically significant (p=0.456).

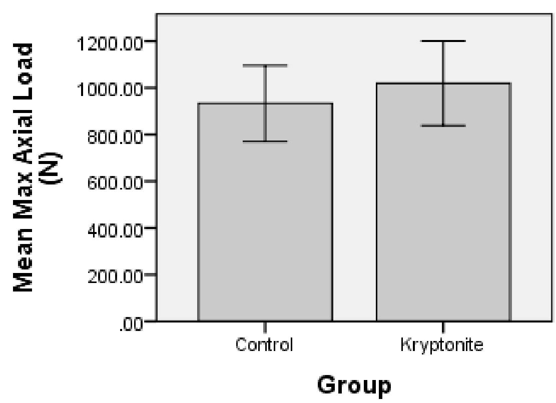

Figure 3. RCF mean max axial load (Error bars 95% CI)

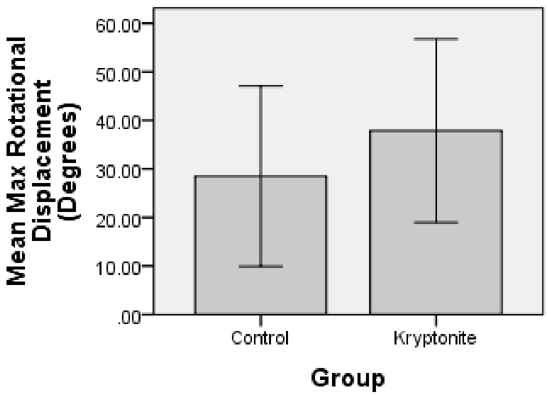

Figure 4. RCF mean max rotational displacement (Error bars 95% CI)

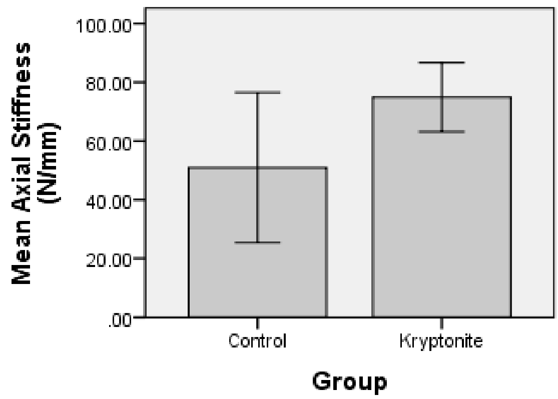

Figure 5. RCF mean axial stiffness (Error bars 95% CI)

Close observation of the test specimen indicates that the humeral head attachment to the proximal locking plate was more stable for the kryptonite group. As such, greater rotational displacement was induced in the Kryptonite group before failure of the head/proximal plate fixation.

The Kryptonite group exhibited a 37.6% increase in mean axial stiffness (Figure 6). The mean difference was statistically significant (p=0.025). This indicates that the Kryptonite group is stronger in the elastic region.

Table 1 summarizes the experimental results for the Compression to Failure test. Table 2 gives the mechanism of failure for each specimen. The 87.5% humeral head failure is expected since it is composed mostly of cancellous bone, which is weaker than cortical bone in axial tension or compression. Thus, a shaft fracture (region of cortical bone) is less likely to fail than the head when subjected to higher loads (which is in agreement with the test results of 1 shaft failure).

Table 1. Compression to failure results

Test Group	Mean Ultimate Load (N)	Mean Rotational Displacement (Degrees)	Mean Axial Stiffness (N/mm)
Cont.	932.9 (±65.43)	28.51 (±7.49)	50.93 (±10.29)
Krypt.	1019.5 (±146.1)	37.89 (±15.22)	70.1 (±6.13)
%Diff	+9.3%	+32.9%	+37.6%
p-val.	0.655	0.456	0.025

Table 2.RCF failure modes

Test Group	Mechanism of Failure
RCF Control (N=3)	2 head, 1 shaft
RCF Kryptonite (N=5)	5 head
Summary	87.5% head only failures 12.5% shaft only failures

3.2. Cyclic compression fatigue

For the CCF test, rotational stiffness values were acquired for cycles 200-700 in 100-cycle increments. The means and standard deviations were calculated and statistical significances were determined for both groups at these cycles. Figure 7 shows the mean rotational stiffness results. Table 3 provides a summary of the results and associated p-values. There were no significant differences in mean rotational stiffness values for cycles 200 (p=0.248) and 300 (p=0.149). There were significant differencesin mean rotational stiffness values at cycles 400 (p=0.043), 500 (p=0.021), 600 (p=0.021), and 700 (p=0.021).The Kryptonitegroup displayed higher means rotational stiffness values than the Control group at all load cycles with statistically significant differences in means above 400 cycles.

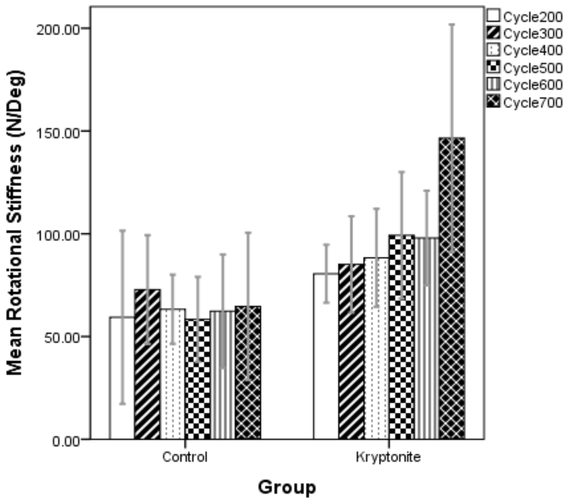

Figure 6. CCF mean rotational stiffness (Error bars 95% CI)

Table 3. CCF summary of mean rotational stiffness

Cycle	Control Mean Stiffness (N/Deg)	Kryptonite Mean Stiffness (N/Deg)	% Change	p-value
200.00	59.35 (±26.48)	80.53 (±8.86)	35.69%	0.2480
300.00	72.83 (±16.63)	85.08 (±14.73)	16.82%	0.1490
400.00	63.28 (±10.57)	88.29 (±14.99)	39.52%	**0.0430**
500.00	58.33 (±12.98)	99.24 (±19.37)	70.14%	**0.0210**
600.00	62.32 (±17.32)	97.94 (±14.44)	57.16%	**0.0210**
700.00	64.64 (±22.51)	146.53 (±34.74)	126.64%	**0.0210**

The Kryptonite group exhibited a 15.9% increase inmean max cycle than the Control group (Figure 8). The mean difference is not statistically significant (p=0.564).

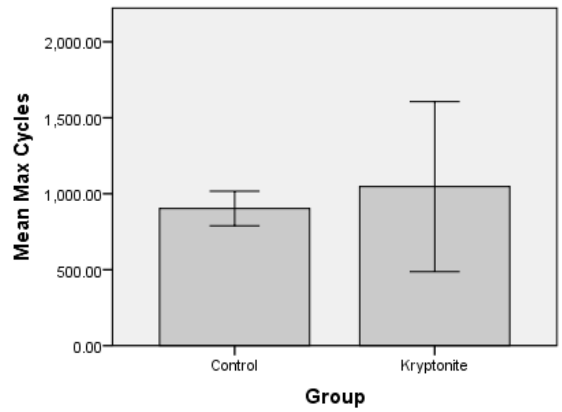

Figure 7. CCF mean max cycles (Error bars 95% CI)

The Kryptonite group exhibited a 68.8% higher mean rotational displacement than the Control group (Figure 8 9). The mean difference is marginally statistically significant (p=0.083).

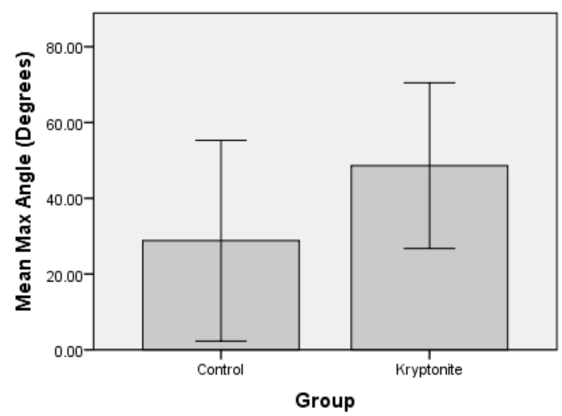

Figure 8. CCF mean rotational displacement (Error bars 95% CI)

Table 4 provides detailed results of the mean maximum cycle and the mean rotational displacement for Control and Kryptonite groups. Table 5summarizes the failure mechanisms of the specimens for the CCF test. The majority of the fixation failure is that of the intra/extra-articular fracture of the humeral head. There was a single Control specimen that suffered a spiral shaft fracture of the proximal third and failure of the humeral head. Figure 10 shows the spiral fracture induced by the cyclic axial compression and constant torque. Figure 11 depicts the differences between proximal humeral fixation failures between the Control and the Kryptonite group. Failures for the Control group exhibited a slow spiral oblique fracture (jagged and rough fracture line) that extends posteriorly and superiorly from the extra-articulate surface screw hole to the inferior intra-articular surface. In contrast, the Kryptonite group demonstrated fracture along the contour of the proximal head plate, which demonstrates the tight bond of trabecular bone to the plate.

Table 4. CCF summary of test results

Test Group	Mean MaxCycle	Mean Rotational Displacement (Degrees)
Cont.	903 (±71)	28.8 (±16.6)
Krypt.	1047 (±352)	48.62 (±13.16)
%Diff	+15.9%	+68.8%
p-val.	0.564	0.083

Table 5. CCF Failure Modes

Test Group	Mechanism of Failure
CCF Control (N=4)	3 head, 1 head and shaft
CCF Kryptonite (N=4)	4 head
Summary	87.5% head only failures 12.5% head/shaft failure

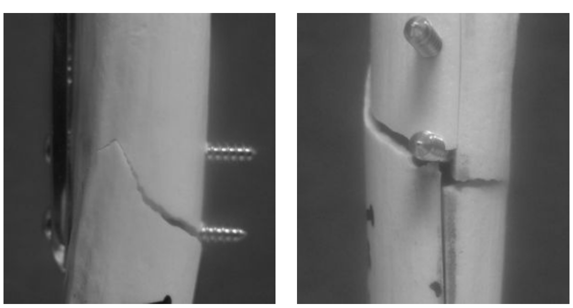

Figure 9. Proximal third humeral shaft spiral fracture (posterolateral and medial views)

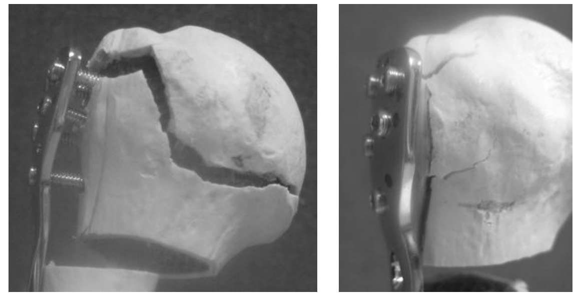

Figure 10. Humeral head failures of Control (left) and Kryptonite (right) (posterolateral views)

4. Discussion

In the proper development of osteosynthesis, stable fracture fixation is required for the prevention of non-union. In addition, osteoporotic bone increases the risk of internal fixation failures [5]. Alternative to conventional methods of internal fixation (pins, screws, and bone plates) is the application of bone cement to the cancellous screwson trabecular bone interface (such as proximal humeral fixation). When coupled with other forms of fixation devices such as proximal humeral plate fixation, pins, or wires, bone cement has been shown to increase strength and stiffness while improving rigid fixation [4-5, 10-11]. However, the polymerization properties of bone cement such as PMMA have been shown to increase the risk of avascular necrosis due to hyperthermic reactionduring the curing phase [6, 12-13].

This study focuses on Kryptonite bone cement, a viable porous biocompatible hypothermic adhesive alternative. With low temperature polymerization, Kryptonite bone cement may pose as an alternative to PMMA and other hyperthermic bone cements. Although many studies have been performed to test Kryptonite bone cement'smaterial strength properties, in vitro anatomical rigid fixation studies on load characteristics are not found in the literature. This study investigates the biomechanical effects of Kryptonite bone cement on proximal humeral fixation.

For all tests, it has been verified that the humeral head is the common failure of proximal humeral fixation (87.5% head failures for both RCF and CCF tests). This is expected, as the humeral head is the region of trabecular bone, which has lower strength properties than cortical bone. However, failures at the head have been observed to have more ductile properties as more energy is required to fail when compared to fracture of the shaft (more brittle in nature).

Although the significant differences in the means of initial stiffness, fatigue rotational displacement, and failure loading cycles have been determined, this study has limitations. Since sawbone models of osteoporotic bone are used, the results do not simulate real osteoporotic bone. The glue line along the lateral diaphysis of the sawbone has been observed to be a weak point and inducement of fixation failure of the shaftthat is unlikely to occur before failure of the humeral head fixation (cancellous bone is weaker than cortical bone). In addition, due to the small number of sample size, statistical significance of other parameters cannot be realized due to sampling error.

5. Conclusions

For both the RCF and CCF test, the Kryptonite group demonstrated higher means of axial compression, rotational displacement, stiffness, and loading cycles. However, only means of stiffness and fatigue rotational displacement were statistically significant between groups. The study also identifies the common failure of cancellous bone (Table 2 and Table 5). Kryptonite bone cement applied to cancellous screws in proximal humeral locking plate fixation, demonstrated positive biomechanical effects of stiffness and fatigue strength. Along with properties of hypothermic polymerization, Kryptonite bone cement pose as a viable alternative bone adhesive that may prevent avascular necrosis in cement aided internal fixation.

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Communicating Product Safety Innovations: When Labels Signal Greater Manufacturer Responsibility

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Abstract

This research proposes that labels associated with safety innovation serve as market signals to consumers regarding manufacturer (versus consumer) responsibility for product safety. The results of a study involving parents purchasing toys manufactured overseas supports this proposition. However, the signaling effect was moderated by consumers' general views on personal responsibility as well as their perceptions of the quality reputation of the country-of-manufacture.

1. Introduction

Manufacturer safety labels often convey information that is considered obvious or, in some cases, unnecessary. Examples include "Remove child before folding" (baby stroller), "Keep product away from infants and children" (animal-shaped neck pillow for children), "Do not allow children to play in the dishwasher" (dishwasher), and "This product moves when used" (children's scooter). Such labels frequently spur discussions among commentators about how manufacturers handle the perceived threat of safety litigation as well as the extent to which consumers versus manufacturers are responsible for product safety.

In theory, the expected costs of product liability motivate companies to engage in efficient levels of product safety and quality innovation [1, 2]. In reality, costs may be too low (leading to disincentives to properly label products) or too high (potentially reducing investments in R&D and thus stifling innovation of new products and beneficial attributes).

From a marketing perspective, investments in product safety innovation can also be considered an example of corporate social responsibility (CSR), defined as an organization's commitment to improve the social wellbeing of stakeholders by deploying discretionary business initiatives and contributions of resources [3]. CSR has gained increasing prominence as marketers have demonstrated its value as an asset that can be leveraged to improve relationships with customers [4]. Specifically, CSR conveys to customers that the company shares certain values with them (e.g., compassion, benevolence), thereby making the company a more attractive relationship partner or source of social identification [5, 6, 7].

In the present research, we examine the impact of using safety labels when communicating safety innovation information on consumers' perceptions of manufacturers' responsibility for product safety. Thus, our focus is not on perceptions of whether manufacturers behave responsibly but instead the extent to which consumers hold them to be responsible.

We propose that safety labels can serve as market signals to consumers that the manufacturer is willing and able to assume responsibility for product safety [8, 9, 10]. However, we further propose that this signaling function only operates under certain conditions. In addition to introducing a new theoretical perspective for studying consumer responses to safety labels, we extend the scope of the literature by examining consumer perceptions of manufacturer responsibility outside of the accident/ injury context.

We next review prior research and develop the research hypotheses. This is followed by an empirical test of the conceptual model in a context where the baseline salience of product safety and safety innovation is relatively high (toys for young children). We conclude with a discussion of the results.

2. Conceptualization

Most empirical research on safety labels has focused on the influence of design factors on a label's communication effectiveness [11]. Such factors include the presence versus absence of a label [12, 13, 14], label location [15], and label complexity and quality [13]. Other studies have examined the role of product attributes in consumer perceptions of safety labels, including the "obviousness" of the safety hazard [12] and the severity of the hazard consequences [9, 12]. Common outcomes assessed in safety label research include product attitudes and willingness to purchase [16], perceptions of risk or safety [17], and allocations of liability for accidents or injury [12].

It is clear that interest in safety labels remains high among researchers and policymakers. Yet, extant literature offers surprisingly little guidance for manufacturers who wish to understand whether and when safety labels impact the extent to which consumers hold manufacturers responsible for product safety. This is particularly true in the context of consumer product search, where no accident or injury has occurred.

We draw on signaling theory to make predictions about the effects of a safety label on consumers' perceptions of manufacturer responsibility for product safety (see Figure 1). In many, if not most, product search scenarios, consumers have imperfect information about unobservable but valued attributes of marketers and the products they offer. As such, consumers often look to marketer behaviors in an effort to infer unobservable attribute values [18, 19, 10]. In turn, marketers attempt to send observable "signals" to consumers to indicate their status with respect to unobservable attributes. Consumers interpret these signals by evoking mental models of marketers' incentives and considering the circumstances in which signals are likely to be credible [20, 21].

For example, consumers have been shown to interpret warranties as signals of product quality, but only for manufacturers with good (versus poor) reputations [8]. This occurs because consumers believe that manufacturers with good reputations are placing a lot at stake (i.e., their reputation) by offering a warranty, whereas manufacturers with poor reputations have little reputational capital to lose by offering warranties on low quality products. Other examples of signals include the level of advertising effort, the choice of retailer(s) in distribution channels, and the use of price-matching guarantees [20, 21].

Similarly, safety labels may serve as potential signals to consumers regarding the extent to which the manufacturer assumes responsibility for ensuring product safety.

Whether consumers believe or use these signals depends on other inputs consumers may use to decide how responsible to hold manufacturers. We consider two such inputs: (a) the consumer's perception of their own responsibility for ensuring product safety and (b) the consumer's general, pre-existing perceptions of the quality of the manufacturing context (operationalized in this research as the country-of-manufacture).

In the absence of safety labels, we expect consumers to exhibit the "norm of even-handedness" when assessing the extent to which manufacturers bear primary responsibility for the safety of products [22]. This norm holds that individuals feel compelled to apply principles in a consistent manner across comparable parties in arrangements where self-interest or preference might dictate otherwise. Adhering to this norm affords the individual feelings (or the appearance) of fairness. In the current context, this suggests that when considering the locus of responsibility for product-related safety, consumers will tend to hold manufacturers to a level of responsibility similar to the level they hold themselves, thus leading to a positive relationship between consumer perceptions of self- and manufacturer-responsibility.

However, we propose that when manufacturers use safety labels to communicate product safety innovations, the norm of even-handedness is less operative because the safety labels serve as a signal of the manufacturer's willingness and ability to take on greater responsibility for product safety. Thus, we predict:

H_1: In the absence of a safety label, perceived manufacturer responsibility significantly increases as perceived personal responsibility increases. When a safety label is present, this relationship significantly diminishes.

Consumers often make inferences about a product based on their perceptions, beliefs, or feelings about its country-of-manufacture [23]. Such inferences tend to be product category-specific and country-specific and can become more pronounced based on cultural differences and political climates. When consumers perceive a country-of-manufacture as having a higher (i.e., acceptable) reputation for product quality, we expect safety labels to serve as credible signals of manufacturer responsibility for safety.

However, consistent with prior research on warranties and returns [8, 21], we expect consumers who perceive a country-of-manufacture as having a relatively low reputation for quality to view safety labels as low-information signals. This occurs because consumers view manufacturers who are operating in lower quality contexts as having less to lose by sending false signals than manufacturers who are operating in higher quality contexts. Thus, we predict:

H_2: In the absence of a safety label, perceived manufacturer responsibility significantly decreases as perceived product quality increases. No such decrease occurs in the presence of a safety label.

3. Study

3.1 Participants, design, and procedure

The context that we selected for empirically testing the conceptual model was U.S. parents who were considering purchasing toys manufactured in China. We recruited a sample of adults who had legal custody of at least one child aged two to four years old. Four trained field study administrators invited every third adult who exited a major children's retailer to participate in the study. Upon agreeing to participate, each person signed a consent form that was then physically separated from the (unsigned) survey instruments in order to maintain anonymity. Copies of the consent form were made available to the participants. Sampling was spread across time-of-day and continued until the predetermined sample size of 90 was reached. Of the participants, 67% were female, 53% percent had one child, 32% had two children, 9% had three children, and 6% had four or more children. The average level of reported spending on toys per child in the preceding year was $246.84 (s.d. = $136.70).

Participants were randomly assigned to one of two experimental conditions. In the "Label absent" condition, participants read a short scenario in which they were asked to imagine shopping for toys as holiday gifts for their child. They were further asked to imagine that they had narrowed the options down to a set of three toys, described as ranging in price from $10 – $135 and being manufactured in China for a U.S. company. The price range was based on the distribution of actual toy prices in the local retail area and was used to encourage parents to consider a variety of toy categories. Participants then read a short article describing how the manufacturer has proactively addressed recent product recall issues stemming from problems at overseas manufacturing plants by developing innovative design and production processes to ensure toy safety. Moreover, the article indicated that the costs of the additional safeguards had contributed to a 30% increase in toy prices.

Participants in the "Label present" condition received the same scenario description and same safety article but were also shown an example of a product safety label associated with the manufacturer's safety innovations. The safety label simply listed the recommended age, potential hazards (e.g., product status with regards to small parts, flammability, lead, and construction materials), and the country of manufacture (China). The layout of the safety label was patterned after the U.S. Food and Drug Administration's "nutrition facts" panels for food items. The safety label was selected based on a pretest involving 30 parents. In the pretest, participants rated the safety label design on five dimensions. Two dimensions were measured using nine-point Likert items, one assessing the label's ability to gain attention ("The label would grab my attention" and the other assessing the label's readability ("The label was easy to read"). The item anchors were 1 = Strongly disagree and 9 = Strongly agree. Three nine-point semantic differential items measured the label's perceived clarity (1 = Not clear, 9 = Very clear), helpfulness (1 = Not helpful, 9 = Very helpful), and realism (1 = Not realistic, 9 = Very realistic). The results indicated that the safety labels were satisfactorily constructed. Specifically, participants rated the safety label design as significantly above the scale midpoint ("5") on each evaluative dimension ($M_{attention}$ = 8.2, $t_{29} = 4.43$, $p < .01$; $M_{reading} = 7.3$, $t_{29} = 8.49$, $p < .01$; $M_{clarity} = 6.7$, $t_{29} = 7.94$, $p < .01$; $M_{helpfulness} = 7.5$, $t_{29} = 4.43$, $p < .01$; $M_{realism} = 6.5$, $t_{29} = 4.05$, $p < .01$).

After viewing the scenario materials, participants completed the study measures and were debriefed.

3.2 Independent and dependent measures

The focal dependent variable, perceived manufacturer responsibility, was measured using a nine-point Likert item (1 = Strongly disagree, 9 = Strongly agree) with the stem "I feel that it is the manufacturer's responsibility to ensure that the toys my child comes into contact with are safe." A similar Likert item was used to measure participants' perceived personal responsibility for product safety, with the stem "I feel that it is my responsibility to ensure the toys my child comes into contact with are safe."

Participants' perceptions of China as a country-of-manufacture was measured with a nine-point semantic differential item that was introduced by the stem "My belief about toys made in China is that they are…" and anchored by 1 = Low quality, 9 = High quality.

3.3 Manipulation check

The success of the label absent/present manipulation was checked at the end of the survey by asking participants whether or not they had been shown a safety label as part of the study. Of the participants who were exposed to the safety label, 100% correctly recalled the exposure. Similarly, 90.0% of the participants who were not exposed to the safety label correctly indicated a lack of exposure. One-sample proportions tests without continuity correction confirmed that each percentage was significantly greater than the chance or "guessing" level of 50% (p's < .01).

3.4. Model testing

The conceptual model in Figure 1 was tested using a moderated multiple regression approach with perceived manufacturer responsibility as the dependent variable. The predictor variables were label (0 = label absent, 1 = label present), perceived personal responsibility for product safety, perception of the country-of-manufacture, the interaction between label and perceived responsibility, and the interaction between label and country-of-manufacture.

The overall model provided a strong fit to the data ($R^2 = .79$; $p < .01$). Further, examination of the regression coefficients (see Table 1) suggests strong empirical support for the conceptual model. Consistent with the norm of even-handedness, consumers who accepted greater personal responsibility for product safety also tended to assign greater responsibility to manufacturer. However, as predicted in H_1, this tendency was significantly diminished (i.e., less positive) when the manufacturer used safety labels (label absent: $\beta_{\text{personal responsibility}} = 1.00$, $t = 12.15$, $p < .01$; label present: $\beta_{\text{personal responsibility}} = .45$, $t = 2.20$, $p < .05$; interaction: $\beta_{\text{label} \times \text{personal responsibility}} = -.55$, $t = -2.15$, $p < .05$). To assist in the interpretation of this effect, we plotted predicted values from the regression model (see Figure 2) at the median level of country-of-manufacture perceptions ("4") and the 10th and 90th percentiles of perceived personal responsibility (values of "6" and "9" for "Lower" and "Higher", respectively).

Also, as predicted in H_2, we found that while consumers assigned lower responsibility for product safety to manufacturers as perceptions of the country-of-manufacture were higher, the effect was not observed when the manufacturer used safety labels (label absent: $\beta_{\text{country-of-manufacture}} = -.23$, $t = -3.38$, $p < .01$; label present: $\beta_{\text{country-of-manufacture}} = .26$, $t = 1.63$, $p = .11$; interaction: $\beta_{\text{label} \times \text{country-of-manufacture}} = .49$, $t = -2.15$, $p < .05$). Figure 3 shows the predicted values for the regression model at the median level of perceived personal responsibility ("7") and the 10th and 90th percentiles of perceptions of country-of-manufacture (values of "1" and "5" for "Lower quality" and "Higher quality," respectively).

4. Conclusions and contributions

The marketing concept has evolved from viewing consumers as exchange partners [24, 25] to viewing consumers as potential relationship partners [26, 27, 28] and "co-creators" of value [29, 30, 31]. Thus, it is perhaps not surprising that the CSR narrative has shifted from whether and when corporations are liable or complicit in their interactions with immediate stakeholders, to whether corporations are responsibly managing their sphere of influence as a socially connected member in a global network [32, 33]. Yet, much of the discussion has taken place in isolation from empirical evidence of how consumers actually process and interpret CSR cues.

Our research takes a step in this direction by examining how consumers integrate perceptions of their own responsibility with perceptions of a product's country-of-manufacture with the potential "signal" of safety labels to arrive at judgments of the manufacturer's responsibility for product safety. Whereas prior work on manufacturer safety labels has focused on consumer perceptions of responsibility after an accident or injury has occurred, we considered the more common scenario where product safety is salient but no accident or injury has occurred (e.g., pre-purchase product consideration). Building on prior applications of signaling theory in the marketing literature, we develop and test a model of safety labels as signals of manufacturer responsibility. We find that when safety labels are not present during product search, consumer perceptions of manufacturer responsibility for product safety increase with perceptions of personal responsibility and decrease with perceptions of the quality of products in the country-of-manufacture.

The findings hold implications for managers tasked with communicating decisions regarding safety-related CSR initiatives in self-regulation contexts. For example, the use of safety labels may change the marketplace positioning and competitive landscape of the company, even when its safety practices remain constant. In the absence of safety labels, safety-oriented positioning may appeal primarily to consumers already high in perceived personal responsibility or who associate the country-of-manufacture with low product quality. However, the use of safety labels – even those that simply serve as a summary of a company's known safety practices – may be sufficient to encourage a majority of consumers in the market to hold companies more responsible for product safety.

Our findings also represent a new data point in the analysis of whether product liability helps or hinders product safety and innovation [1, 2]. Specifically, our findings suggest that the introduction of safety labels may breed a behavioral obstacle to innovation (even, ironically, if the innovation pertains to product safety) by elevating expectations of company responsibility. This is most likely to occur when consumers perceive that products are generally of acceptable quality in the country-of-manufacture or when their perceived personal responsibility is low.

5. Limitations

This research is not without its limitations. First, while the toy manufacturer context was ideal for conducting an initial test of the conceptual model, caution is urged in generalizing the effects to other product categories and contexts. Second, future research may wish to gather evidence regarding the proposed cognitive mechanisms that drive perceptions of manufacturer responsibility (e.g., signal interpretation). Third, our sample consisted of parents of young children who were "intercepted" while shopping at particular locations. These parents may differ systematically from parents who primarily shop at other locations or online.

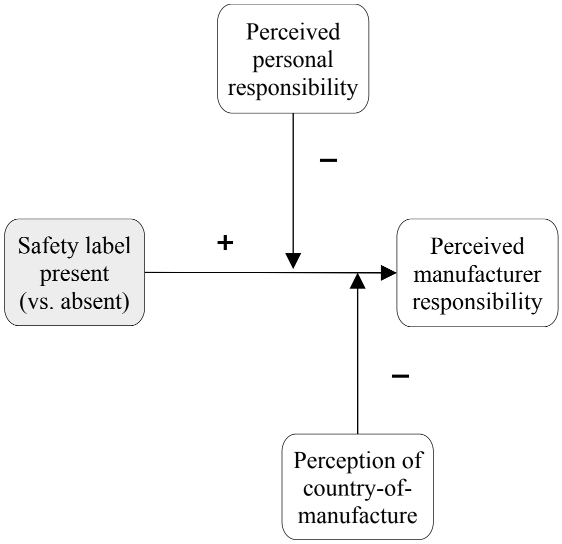

Figure 1. Conceptual model of the effects of safety labels on perceived manufacturer responsibility

Figure 2. Moderating effect of perceived personal responsibility on signaling by safety labels

Figure 3. Moderating effect of country-of-manufacture on signaling by safety labels

Table 1. Moderated multiple regression results

Parameter	*Beta*	*s.e.*	*t-value*
Intercept	.32	.78	.41
Personal responsibility	1.00	.08	12.15**
Country-of-manufacture	-.23	.07	-3.38**
Label (0 = absent, 1 = present)	3.72	1.81	2.05*
Label × Personal responsibility (H_1)	-.55	.26	-2.15*
Label × Country-of-manufacture (H_2)	.49	.20	2.48*

Dependent variable: perceived manufacturer responsibility
Model fit: R^2 = .79**; *Sig. at .05 level; **Sig. at .01 level

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Concrete Tilt-Up Construction: Bringing Real World Applications into the College Classroom

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Abstract

The tilt-up construction market has demonstrated substantial growth from 1995 to 2011. Since 1995 the square feet of walls placed has increased from 129,000,000 sf to over 300,000,000 sf. With this increased amount of work comes the demand for skilled labor and management. Pittsburg State University with the help of Crossland Construction Company of Columbus, KS and the Kansas Department of Commerce through a Workforce Development grant has developed a tilt-up concrete seminar to train employees unfamiliar with tilt-up. Pittsburg State University and Crossland Construction Co. developed a three day (24 Hour) seminar that included class room training and field training. Pittsburg State University and Crossland Construction Co. researched available training seminars and concluded that no other training included the actual placement and lifting of concrete panels. The two parties also researched which certifications upon completion that the participants would be eligible to receive. Two institutions had such certificates available, NCCER (National Center for Construction Education and Research) and ACI (American Concrete Institute). Together Crossland Construction Co. and PSU developed a program that would be able to train both the general population workforce and students within Pittsburg State University in the practices of tilt-up concrete including the placing and lifting of the concrete.

1. Introduction

This collaboration between Pittsburg State University, Crossland Construction Co., Kansas Department of Workforce Development came about due to the need of a workforce and management positions with knowledge in Tilt-Up Construction. This training was to go into more depth than currently offered by programs offering training in tilt-up concrete construction. This program was designed for the participants to cast and erect panels within the seminar. The Kansas Department of Commerce annually awards funding for grants to train underemployed persons in an area of need within all sectors of industry through Workforce Solutions Funding. Together PSU & Crossland approached the KDoC for a three year grant with an approximate value of $120,000 to train 300 persons over this timespan. The KDoC sent a counter offer to award one year of the program with an approximate value of $42,000 with a matching 50% donation from Crossland Construction and Pittsburg State University to train 100 persons within the one year time span free to the participants. PSU, Crossland and KDoC agreed to these terms to become the first partnership between the KDoC and 4-year institutions in the State of Kansas.

2. Research

Researching for this grant uncovered that there are two organizations that offer training in tilt-up for certification. They are the American Concrete Institute and the National Center for Construction Education and Research. ACI has two levels of certification and the NCCER has one level of certification. ACI's certifications are the Tilt-Up Supervisor and Tilt-Up Technician.

" A Tilt-Up Supervisor is a person who has demonstrated proficiency in and an understanding of overall on-site administrative and technical management for producing tilt-up projects by passing the ACI written examination and meeting work experience requirements.

A Tilt-Up Technician is a person who has an understanding of overall on-site administrative and technical management for producing tilt-up projects by passing the ACI written examination, but who lacks sufficient work experience to qualify as a tilt-up supervisor." [1]

To achieve certification from ACI a written exam must be taken for either level. This exam covers 10 areas of knowledge. They are Safety, Plan Reading, Scheduling, Site Preparation & Foundations, Slabs on Grade, Layout, Forming, Concrete Properties & Placement, Erection, and Structural Systems. The difference in the two certifications is the amount of practical experience needed to qualify for the Tilt-Up Supervisor. Applicants must have a minimum of 2000 hours spread among the 10 areas of knowledge.

To achieve completion of the NCCER module of tilt-up a participant must complete approximately 20 hours of in class training, a written quiz and a performance exam must be completed. The written quiz covers 11 areas of competencies: Describe the different processes used in installing tilt-up wall panels, Explain the importance of the casting bed, Identify and install the various types of lifting eyes used in forming tilt-up panels, Identify the special rigging requirements for tilt-up wall panels , Identify the different methods of forming tilt-up wall panels, Demonstrate the different methods of forming tilt-up wall panels, Prepare for the erection of tilt-up wall panels, Install proper bracing for tilt-up wall panels, Erect and properly align tilt-up wall panels, Install embedments, blockouts, architectural finishes, lifting devices, and reinforcing materials using a set of construction drawings, Describe the final grouting procedure. For the performance exam the participant must form a tilt-up panel in accordance with a drawing provided by the instructor and install inserts, reinforcement, and reveals.[2]

Cost of the two programs was also considered. To take the exam from ACI a participant would need to buy the book and pay for the exam. The book cost is $130 and the cost for the exam varies from area to area but is approximately $150. To take the quiz from NCCER the participant must at a minimum purchase the individual module from the Level 3 Carpenter Book at a cost of $25.33. While considering cost to the program the decision was made to use NCCER as the template.

Also researched were the types of panels, footings, openings, inserts, and lift applications that were available to complete a tilt-up project. Based on these findings we incorporated into the drawings for this project spot and continuous footings, butt and miter corner joints, various door and window opening in locations of the panels into seven panels. Below you can view a profile picture of the panels erected into place. Also incorporated into the design was the placement of panels using stiffbacks, panel to slab braces, and bracing to a metal structure. The panels were also designed to be portable so that the seminars may be offered on a company's site if so desired. The panels are 5' wide, 12' in height and 5" in thickness with an average weight of 3,600 pounds. The metal structure is 11' in height, 10' width and 5' depth with an approximate weight of 400 pounds. Keeping everything light also allows for a smaller crane to be used.

3. Methodology

PSU wanted to allow participants to be able to take both exams if so desired. Keeping this in mind is how the formatting of the class came about. After researching the time needed for both of the programs PSU wanted to loosely base the program around the requirements of the NCCER Tilt-Up Module while also incorporating the needed information from ACI. This would allow participants to take the NCCER quiz at the end of the seminar and also allow them to take the ACI Tilt-Up Technician exam on their own if they so desired.

The initial goal was to have between 15 and 25 students per sessions and offer 5 sessions to choose among. These sessions were to be open to PSU students, KDoC unemployment offices, and area contractors.

The first seminar was designed to be 24 hours in length. The design included 12 hours of classroom training and 12 hours of lab experiences. Classroom training included areas of introduction, history and current trends, fundamentals of forming, preparing for concrete placement, site organization, panel lifting, plan reading, and safety within the classroom setting. After each classroom section there was a 10 – 20 question quiz to prepare the participants for the final test. Lab experiences included layout of formwork and inserts, rebar placement, forming panels, insert placement, bracing of panels, and panel erection.

The first seminar had 8 participants. This number proved to be an ideal number for a test run of the seminar to start with. This allowed for working out the estimated times and sequencing for the larger seminars. We began the session on a Wednesday evening with a 4 hour time block, 8 hour days on Thursday and Friday, and a 4 hour session Saturday.

Wednesday evening began with checking in, introductions of staff, safety items, expectations of the class, attire that would be needed for the lab sections of the class. Lectures for the evening included, history and current trends of tilt-up, site organization, and a safety presentation for labs to be covered in the morning. Items covered in these lectures included current world records for panel types, statistics of square feet of panels placed, locations of casting beds, crane placement on site.

Thursday and Friday lectures and labs included fundamentals of forming, preparing for concrete placement, plan reading, panel lifting, layout of formwork and inserts, forming panel, rebar placement and safety. Items that were completed or discussed include: reading detailed rebar plans and placement of rebar from the plans; calculating spacing, location, and diagonals needed to place formwork; reviewing of Dayton Superior insert placement manuals, load requirements and location of inserts. This was followed by performing the layout and placement of the inserts and required extra rebar, placement of bond breaker, and calculation of loads placed on crane and proper crane selection.

Saturday started with a toolbox safety topic, safety concerns such as pinch points, and starting positions were given. The class was then divided into two sets of starting positions. The starting positions were either handling of panels or performing layout and leveling of panels. Handling of panels included rigging, placement of braces onto panels, and erection of the panels. The layout and level included setting alignment, setting shim packs, and pluming of the panels. At approximately the half-way point the groups switch respective duties. The total process was completed when the erected panels were torn down and made ready for the next seminar.

4. Results and Discussion

As a result of the first and second sessions we were able to remove items that were covered twice by the faculty and become more efficient in the classroom delivery. We were also able to better gauge the needed time to complete the lab portion of the class. This resulted in the last section being completed in 16 hours.

Among the unintended effects of this seminar were the ancillary items that the participants were able to learn. Many of the participants had little to no experience in construction. Items such as learning how to use a scissor lift, setting up of a total station, use of an auto level, use of fall protection systems, and rigging of a crane were items that utilized by the participants. These items were discussed as being nice to know how to use because they had seen these items on jobsites but not been able to work with them.

5. Conclusion

The partnership between Pittsburg State University, Crossland Construction Co., Kansas Department of Workforce Development allowed for the first lifting and placement of panels known in the United Sates. This was also confirmed by the Tilt-Up Concrete Association. Participants took pride and ownership in the fact that they were completing an item that had not been done to date and were very involved when completing the hands on portions of the class. The original goal of offering the class to 100 participants was not met. The course ended with 96 participants having taken advantage of the program. The success rate was 100%, all 96 having passed the NCCER Tilt-Up Module Quiz. To date we are not aware of anyone completing the ACI Tilt-Up Technician Exam.

Pittsburg State University has continued to offer this course within The School of Construction's Methods of Concrete and Masonry class. Through this departmental course there has been an additional 118 participants.

References

[1]http://www.concrete.org/certification/Cert_pgminfo.asp?pgm=Tilt%2DUp+Supervisor+%26+Technician [accessed July 2012]

[2]NCCER (2009), Carpentry Forms Level 3 Trainee Guide, Looseleaf, 4th Edition.


TEREX


CROSSLAND

Rapid Prototyping: Design of a Recycling System for the Cupcake 3D Printer

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Abstract

This paper presents the design and development of the Cupcake 3D CNC printer, a special class of machines designed for the automated construction of physical objects using additive layer manufacturing technology. The printer system is great for fabricating parts and designs that are not available on the open market. It prints with Acrylonitrile Butadiene Styrene (ABS), High-Density Polyethylene (HDPE) and Polylactic Acid (PLA) plastics. To print a design, the printer platform moves in the X-Y plane and the extruder along the Z-axis with precision stepper motors while the extruder continually places a small stream of melted ABS. The recycler's addition to the printing system provides a way to reduce cost and make the system more environmentally friendly. A rotating auger bit inside an enclosure barrel forces the particulate down the tube. An electric motor turns the auger which grabs the material to move it down the barrel. Prototype of this design and the 3D printer were fabricated and tested for proper functionality. Samples printed using the 3D printer, the advantages of the recycling system, the difficulties encountered during the design and development, and recommendations for future recycling system design are presented and discussed.

1. Introduction

Rapid prototyping (RP) consists of a family of unique fabrication processes developed to make engineering prototypes in a minimum possible lead times based on a computer–aided design (CAD) model for the item [1]. The variety of rapid prototyping technologies arise because product designers would like to have a physical model of a new part or product design rather than a computer model or line drawing [2]. Three-dimensional (3D) printing builds the part in a usual layer-by-layer fashion using an ink-jet printer to eject an adhesive bonding material on to successive layers of powders [3].

The MakerBot Cupcake CNC 3D printer is of a special class of machines designed for the rapid prototyping and manufacturing of physical objects using additive manufacturing technology. The Cupcake is one of many models available in the open source community. The main purpose of designing and developing a 3D printer is to demonstrate additive manufacturing technology to students. The Cupcake was chosen over more reliably printing and accurate commercially available CNC printers because of a very significant price difference. Currently, the most affordable commercial additive fabrication machine is available from Hewlett Packard (HP) and Stratasys called the uPrint personal 3D printer. These HP-Stratasys printers were released in Europe on April 19, 2010 with a basic price at $14,900 [4]. The ABS refills for these machines cost around $200 [5]. The MakerBot Cupcake currently costs $750 for the basic kit and 1 lb of ABS filament costs $15 for any color [6]. The initial cost of a MakerBot Cupcake is 5% of the initial cost of the uPrint. Also, the continuing costs of ABS refills are only 7.5% of the cost of refills for the uPrint. This drastic cost difference makes the difficulties involved with using the MakerBot worthwhile [7, 8].

MakerBot uses high quality laser precision cut parts as well as parts fabricated by the Cupcake. The build platform and extruder move with precision stepper motors and the extruder continuously places a small stream of melted Acrylonitrile Butadiene Styrene (ABS). Any model, within the build limitations of 4in x 4in x 6in, generated in a CAD program that exports a Stereo Lithography file (.stl) can be converted to G-codes using Skeinforge [6]. Like most CNC machines, the Cupcake is driven by G-codes. The program ReplicatorG is freeware that is designed to drive the Cupcake. The ReRap (Recycling System for Rapid Prototyping) addition presented is based on an external ABS recovery system that complements the Cupcake 3D printer by converting scrap ABS to a 3mm filament to be used by the Cupcake 3D printer. The ABS recovery system's addition to the 3D printing system provides a way to reduce cost and makes the system more environmentally friendly [7].

2. Background

In the year 2005 the RepRap Initiative was launched by Dr. Adrain Bowyer from the University of Bath with the intention to make 3D self replicating machines 'freely available for the benefit of everyone'. The first open source 3D printing machine was released in March 2007 by the RepRap initiative (RepRap.org). Many companies have developed affordable 3D printers and supplies using the information provided from the RepRap initiative. One of these companies is MakerBot, Inc. MakerBot (founded in January 2009) developed a desktop 3D printer called the Cupcake [6]. MakerBot Cupcake number 489 was purchased for the Mercer Engineering Education Entrepreneurship Program. The ReRap team consisted of 2 mechanical engineering students (Luke Cox and Carrie Wheeler), an electrical engineering student (Sharon Dawson), and a computer engineering student (Aaron Coonce) [7, 8]. To support the ReRap student design team's efforts, an academic technical advisory team consisting of five faculty members from various engineering discipline was provided by Mercer University School of Engineering (MUSE). Their involvement and encouragement in this endeavor has been a key component to this project's development and success. Each student on the ReRap engineering team has an advisor specific to his or her field. This advisory team has enabled the ReRap team members to improve their performance through their constructive feedback and support throughout the project period.

Dr. R. Radharamanan, Professor of Industrial and Systems Engineering and Director of Mercer Center for Innovation and Entrepreneurship, served as the client and technical advisor for all students throughout this project and provided the necessary funds from the Kern Family Foundation grants to purchase the Cupcake 3D printer and necessary materials and supplies to design, build, and test the recycling system. He has Ph. D. in Industrial Engineering from Catholic University of Leuven, Belgium. His research interests include: design and manufacturing, automation and robotics, facilities design, innovation and entrepreneurship, and rapid prototyping.

Dr. Loren Sumner, mechanical engineering faculty, served as the senior design course instructor and technical advisor for the mechanical engineering students (Cox and Wheeler). He obtained Ph.D. in Mechanical Engineering from Georgia Institute of Technology. His research interests include:

mechanical systems, thermodynamics, heat transfer, and fluid mechanics.

Dr. Kunz, mechanical engineering faculty, has Ph.D. in Engineering Science from Georgia institute of Technology. He served as technical advisor to the mechanical engineering students (Cox and Wheeler). His research interests include: mechanical systems, design, materials, and composites.

Dr. Kevin Barnett, electrical engineering faculty has the following credentials: Ph.D. Electrical, Electronics and Communications Engineering from Clemson University and served as technical advisor for the electrical engineering student (Sharon Dawson). His research interests include: circuits, feedback controls, digital signal processing, and modeling of electrical systems.

Dr. Anthony Choi, computer engineering faculty, served as technical advisor to Aaron Coonce. He has Ph.D. in Electrical, Electronics and Communications Engineering from University of Florida. His research interests include: embedded systems, programming, and robotics.

The Rewrap student team researched the 3D printing alternatives to learn about how 3D printing is accomplished, what resources are required to maintain it for the user, and which 3D printing system is the most reliable. One of the major unaddressed concerns of the owners of open source 3D printers was the waste associated with printing and how the waste can be recycled or reused. Even if a print comes out perfectly there are support materials for any overhang structures and a grid that helps the part grip the surface that it is printing on. In the learning process also many misprint can occur (Figure 1).

(a) (b) (c)

Figure 1. Waste in 3D printing - (a) support materials, (b) misprints, and (c) grid material

The overall learning objectives for the ReRap student team include the following:

- Design, build, and test the MakerBot Cupcake 3D CNC printer.
- Print prototypes of complex and difficult to machine parts using the 3D printer.
- Design, build, and test a recycling system to convert the scrap ABS from the Cupcake printer to a 3 mm filament for reuse and print new parts and prototypes.
- Provide easy to use operating instructions for the 3D printer and the recycling system.

3. MakerBot 3D Printer

The MakerBot consists of a wooden frame, a build platform with X and Y pulleys for movement, and a Z platform on which the extruder sits. The extruder, and the X, Y, and Z stepper motors all have a circuit board which is connected to the Cupcake's mother-board. The MakerBot circuit board details are shown in Figure 2.

Cupcake uses additive technology to form 3-D parts, which is ideal for prototyping and manufacturing a small number of parts. Additive technology provides the capability to print interior structures.

The steps taken to achieve successful operation of MakerBot include: downloading software; testing motors independently for vibration and backlash; testing extruder for idler wheel and heater barrel; and printing misprints or successful prints.

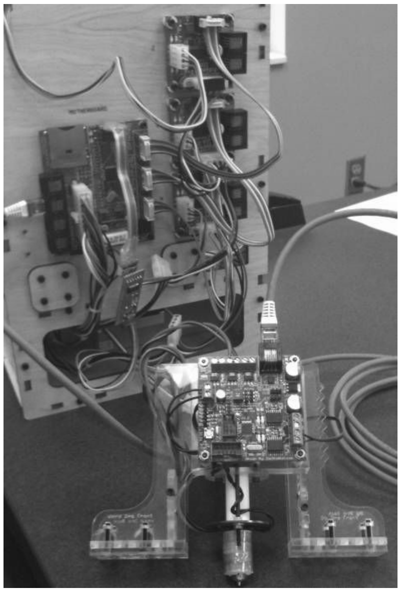


Figure 2. MakerBot circuit board details

Throughout this process of testing it was necessary to troubleshoot several issues. This involved constantly verifying the assembly by referencing the MakerBot website [6]. Adjustments that are unique to this machine, such as the idler wheel grip, were also determined on an ongoing basis.

3.1. Downloading software

To use the Cupcake, any 3D modeling software that can export a stereo lithography file (.stl) may be used. AutoCAD and Pro-ENGINEER programs can export this file type. Free software for 3D modeling that many in the MakerBot community use is Blender. The software can be found at http://www.Blender.org/. The only limitation is that the 3-D model be within the 4in x 4in x 6in build area.

From the stereo lithography file, G-codes are produced. The G-codes drives the machine. To convert the stereo lithography to G-codes, Skeinforge is used. Skeinforge will automatically center a model on the X, Y and Z axes and determine the raft size for the print. It will maintain the same orientation within the X, Y and Z planes. Skeinforge has several settings which can be changed to optimize the performance. The version downloaded was optimized for a MakerBot Cupcake CNC in general, but not adjusted for optimization of this Cupcake machine. ReplicatorG is used to control the machine by delivering the G-codes to print the parts and perform test extrusions. Both ReplicatorG and Skeinforge may be downloaded at http://replicat.org/download. ReplicatorG was downloaded to test the MakerBot Cupcake through its control panel.

The G-codes for the whistle was downloaded directly and the whistle was printed successfully. This was the first object printed [9]. The next step was testing Skeinforge. For the rest of the prints, stereo lithography files were downloaded, converted with Skeinforge, and then printed through ReplicatorG.

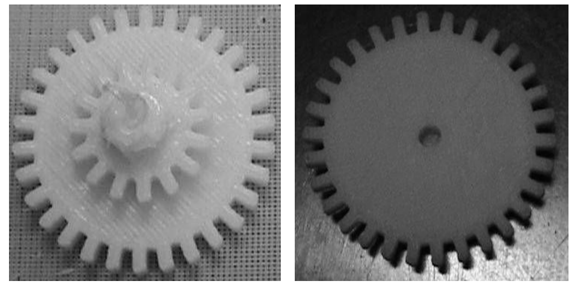
3.2. Testing motors independently

After downloading ReplicatorG and connecting the MakerBot Cupcake, the control panel was used to test the X, Y, and Z motors. This testing revealed that the X and Y motor control hardware was switched, so the necessary connections were changed so that the motors were all connected to their proper controllers. Further testing revealed that both the X and Y motors were running in reverse. The motors were inverted by using the ReplicatorG software so that after testing all motors moved the correct platform in the correct direction when prompted by the ReplicatorG control panel. To test full functionality of the motors, a simulation print was performed.

3.2.1. Vibration: The G-codes for the whistle was downloaded and a simulation was run to test the motor performance. The extruder was disconnected to isolate the testing to the movement of the platforms. Loud and visible stuttering and excessive vibration were noted during the test run. The tension on the X-direction pulley belt was adjusted and this reduced stuttering. Vibration has continued to be an issue. Vibration decreases precision of the filament placement, so a clean print is not achieved. The inherent vibration of the stepper motors over time loosens the nuts on the pulley system. The pulleys have been repeatedly checked for tension, and adjusted as needed. Lubrication was added to the rods to aid in vibration reduction.

3.2.2. Backlash: Tightening pulleys has reduced vibration, however since one side of the pulley remains slack, there are also backlash issues. A test to determine how much backlash was performed by moving the platform in one direction until it was fully taunted and then reversing direction with a small jog size. The number of steps that were required before the platform moved equated to the backlash distance. It was found that in both the X and Y pulleys there were 0.4mm to 0.5mm of backlash respectively. Research revealed that the Skeinforge default for backlash, which it calls 'lash', is 0.2mm [10]. This explains why a cleaner print was not achieved. The pulleys were tightened so that both sides were taunted and have 0.2mm backlash. Each MakerBot Cupcake machine has its own optimal settings, and vibration can further be reduced by determining the optimal pulley tension, resulting backlash, and editing software settings.

An example of how vibration and backlash effects a print can be seen in Figure 3. Backlash is especially noticeable when there are several back and forth movements consecutively, as in the top cylinder on the double gear - Figure 3(a). The backlash causes the small hollow cylinder to be printed with the extruded material offset from the intended placement. The center hole, which can be seen in the rear view of the gear, was not maintained, and the outer edges of the top are not clean – Figure 3(b).



(a) (b)

Figure 3. Effects of backlash

3.3. Testing extruder

After initial testing of the motors, the extruder was tested independently. First, the physical set-up within the MakerBot was checked. It was noted that the laser-cut openings in the acrylic for the screw heads were too small. This prevented the screws from being pushed in flush and a nut to be attached on the other side for stability. Sandpaper was used to slightly enlarge each hole so that the screw-heads could fit, and when attached, the extruder could be safely bolted for stability, and the vibration of the stepper motors would not cause extruder motion.

Once the extruder was securely attached to the stage in the MakerBot, it was connected to the MakerBot motherboard with an Ethernet cable. The ReplicatorG control panel was used to test the extruder. The temperature was set at 220 degrees Celsius and the NiCr wire began to heat the heater barrel. The temperature measured by the thermistor is also shown in the control panel as "current temperature". Once the control panel indicated that the heater barrel was at operating temperature, the motor was turned on and a filament fed in to begin extrusion. Alignment issues with the feeding assembly caused the filament to have difficulty in feeding, all the way down to entering the portion of the assembly. An attempt to determine if the thermistor was properly calibrated was made. The temperature was raised in 5 degree increments to 240 degrees Celsius according to the ReplicatorG control panel to see if this aided extrusion. The motor idler wheel was aligned properly and the heater barrel was thoroughly cleaned. After all of the above fixes, the extruder was tested and successfully extruded a continuous extrusion without difficulty or manual aid. Since extrusion was achieved, and the motors had been verified to move correctly during a simulation print, the next step was to run a trial print.

3.4. 3D printing

The previously downloaded whistle code was loaded into ReplicatorG to be printed. The first thing that must be done before printing is setting the zero point. This is a simple matter for the X and Y axes as the nozzle simply needs to be aligned with the center cross mark on the build platform. The Z position has a greater effect on build performance. Using a piece of paper on the build platform, the nozzle is lowered until the paper cannot be moved. The nozzle is then raised by 0.25 mm, which is approximately half of the extrusion diameter. Next, the print is started by clicking G-code->Build in ReplicatorG. The first thing the program will do is to lift the Z platform and heat the heater barrel to operating temperature. After heating to the proper temperature, a small amount of filament will extrude. Remove this test filament with tweezers, and click 'OK' on the dialog box. The Z platform will then lower and the raft will print. The platform will move in an outer rectangle before beginning extrusion. The initial prints encountered issues, and there were three failed prints before a successful print was achieved.

A whistle was successfully printed as shown in Figure 4. In the first print, the interior ball did not come free from the bottom wall, and it is possible that this is a complication of the nozzle being too close to the Z platform at the start of the build, or an error in the G-codes. The whistle is a good example to print because of its interior features. The whistle is hollow with an interior ball, which cannot be achieved using a traditional milling machine.

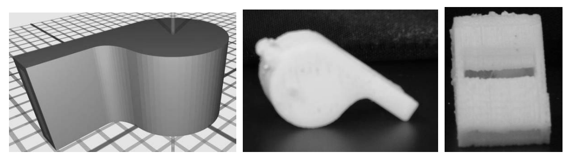
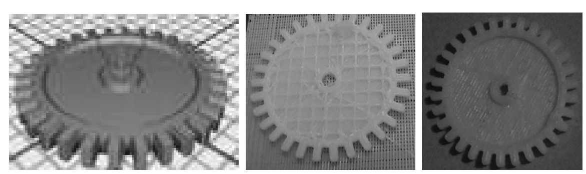
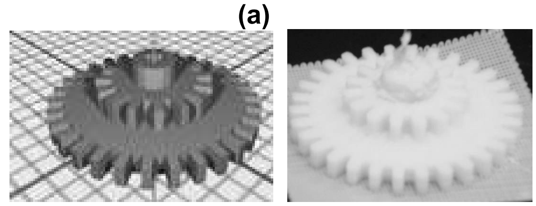


Figure 4. Different views of the whistle.

For the rest of the prints, stereo lithography files were downloaded from Thingiverse.com [11]. The files were converted with Skeinforge and the G-codes were loaded into ReplicatorG. The gears printed have a hollow honeycomb interior, which reduces use of unnecessary ABS filament. This can be seen in the interior of the gear. Both the single and double gears were printed and different views of the gears are shown in Figure 5.



(a)



(b)

Figure 5. Different views of
(a) **single gear and (b) double gear**

4. Recycling System Design [7]

The ReRap Recycling System can be broken down into 3 main components; The ReRap Control Software, the ReRap Electronics System, and the ReRap Body. The ReRap basically functions by taking in scrap plastic, feeding it down a metal pipe using an auger, heating pipe at one end, and forcing the plastic through a 1/8 inch nozzle. The ReRap is completely controlled with software to make interaction with it simple and user friendly.

The ReRap is optimized for use with the Cupcake 3D printer. There are many plastics which ABS is commonly mixed with to improve certain properties. The ABS mixture that the Cupcake 3D printer uses begins to burn at 250^{o} Celsius. Though ABS is not classified as a carcinogen, all chemicals that compose it are known carcinogens [12]. Therefore a thermal failsafe was implemented to cutoff the ReRap if the temperature goes above 240^{o} Celsius.

The 'brain' of the ReRap is an Atmega 328 microcontroller. The microcontroller through the USB port of a computer communicates with the ReRap Control Software. The microcontroller reads the signals from the thermistors and sends the information to the ReRap TempMon, it controls the motor speed, and it controls the temperature by using feedback from the thermistors. The ReRap TempMon sends the values of the desired motor speed and temperature to the microcontroller. The microcontroller uses the values set by the user to then obtain the desired speed and temperature. The speed and temperature are controlled by pulse width modulation (PWM).

The power supplied to the heater, motor, and heat sink fans comes from a 12 Volt, 10 Amp computer power supply. With all the electronics fully on about 6 Amp of power is used. The fuses are in series on the 12 volt line. The electronics consist of 4 main components: insulated 80/20 Nickel Chromium wire to heat the nozzle area, 100K thermistors to read temperature, DC motor to push plastic through, and fans to increase the efficiency of the heat sink [7].

For both the motor and heater a MOSFET is used to translate the 5 volts PWM from the Arduino into a 12 volt PWM. Due to the earlier stated hazards of temperatures over 250^{o} Celsius, the circuit was carefully designed to never provide power to the heater and motor unless the Arduino (microcontroller) is 'on' and told to run. This way the ReRap will not function unless values are set for the temperature and motor.

The heating element is two insulated 80/20 nickel chromium wires which are secured directly on the 3/8 inch brass heating barrel section. Both wires must be cut to have 4.5 ohms for the ReRap to be able to reach up to 240^{o} Celsius. To secure the wire, a Kapton tape is rated to handle up to 260^{o} Celsius was used.

The temperature sensing on the ReRap control system functions by reading the voltage division between resistors. One resistor is a known value and the other is a thermistor. A thermistor's resistance varies inversely with temperature. The voltage signal is read across the thermistor and put through an analog to digital converter to feed a value to the software that corresponds to the temperature.

To protect the electronics a 10 Amp fuse was added so that a short in a wire will not melt the hardware. The 10 Amp fuse is in series with the thermal switch. It is the 12 volt line from the computer power supply which is opened to turn off the heater.

The desired motor characteristics were that it had to have high torque and low speed to slowly apply pressure to the molten thermoplastic and move the plastic down the pipe. The motor chosen is a 12 Volt DC gear motor which has a no load speed of 29 revolutions per minute (rpm).

The ReRap body consists of threaded steel pipe, along with a bevy of other components, which screws together and is supported by 3 sections of sheet steel. The body was intentionally constructed so that it would be easy to disassemble in case troubleshooting is required in the future.

The biggest difficulty in forming a working product was the struggle between heating up the nozzle and brass nipple while still maintaining a room temperature environment in the barrel that the ABS travels down. Due to axial heat conduction from the brass nipple to the steel nipple barrel, it was hard to apply heat to just one area as the surrounding area where adversely affected. Hence, a decision was made to apply heat sinks. The problem is the heat sinks dissipated large amount of heat and created too much of an area for the heat to conduct to. This increase in area caused the overall temperature to go down and the system would not reach the desired temperature of 240^{o}C.

Another problem the design team came across was trying to determine the properties of the thermistor which was used for temperature measurement. Finally, since the manufacturer provided no specifications or details about the item, it was difficult to determine the characteristics of the thermostat as well as find other sensors to compare it to. In the end, a thermocouple on one of the team member's home digital multi-meter was used to form a range for the thermistor and this was extrapolated to the operating temperature needed for the design.

Some parts that were made entirely out of scrap metal were the two thermal switch mounts, the two heat sink mounts, and the five thin plates for the body of the machinery. The auger had to be physically altered in order to directly mount it to the motor. In total, ten mechanical parts were either altered or constructed for this design.

The following changes were made to the ReRap to bring the extruder up to temperature. First the heat sink was completely removed. One fan from the heat sink was used to keep the barrel cool. Also the barrel size was reduced from ¾ inch to ½ inch. Consequently, a ½ inch to ½ inch coupling and a ½ inch to ¾ inch coupling were purchased to fit the ½ inch barrel to the extruder. In addition a thin Teflon coating was applied at all joints where heat conduction was undesired. The Arduino and ReRap board of the final functional extruder built and tested to convert the scrap ABS to a 3 mm filament is shown in Figure 6.

5. Conclusions and Recommendations

The Cupcake has been brought to operational status, successful prints were achieved, and user instructions were written. The equipment is sensitive and can easily be damaged by misuse, so use of the Cupcake should be closely monitored. Since the software is Beta, failure of or damage to the machine can occur due to glitches. There are several opportunities to improve the MakerBot Cupcake in the future.

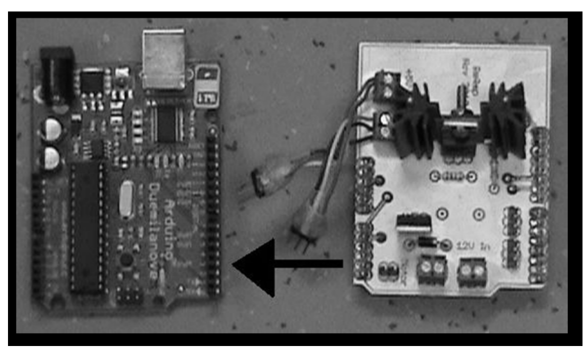


Figure 6. Arduino and ReRap board for the recycling system to convert the scrap ABS into a 3 mm filament [7]

The current solution for converting scrap ABS into 3 mm diameter filament is a screw fed system with sensors monitoring the temperature of the ABS. The components that make up the system function as they should separately. The completely assembled solution is able to obtain target temperature and maintain a temperature within 15 degrees of the range. The ReRap team believes the auger fed extruder system still provides the best solution for recycling the reusable ABS. This device functions but does not produce a filament continuously because the device has trouble reaching the required temperature. Future revisions of this machine should have a more powerful heater that is removable without compromising the heating element. The code for maintaining constant temperature should be further optimized to stay nearer to the target temperature. A better power supply should be used for ease of use. The current screw extruder could still provide an excellent teaching tool for a classroom setting as it showcases the workings of common plastic extrusion processes.

The purpose of this project was to improve upon the MakerBot 3D printer and after working with the printer the ReRap team has more ideas on alternative ways to improve the 3D printing system. First, build a more reliable extruder for the Cupcake 3D printer. The current extruder model has a high failure rate and is often in need of troubleshooting. The ReRap team suggests development of an automated printing system that is capable of printing parts in succession. Currently the user must remove the part by hand and go through a 5-10 minute process between printings. A laser could be added for auto position of the extruder at the origin point slightly above the building platform. A vast number of modifications could be made to improve reliability, ease of maintenance, and add functionality.

The learning objectives of this project were successfully accomplished by the ReRap student team: MakerBot Cupcake 3D printer was built and tested; prototypes and complex parts were designed and made; and the recycling system was built and tested for processing scrap ABS and extruding 3 mm filament for reuse in the 3D printer.

6. Acknowledgments

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Inductive Learning Activities for Process Development and Cost Estimating

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Abstract

Connecting curriculum to practice is one of the more difficult things to do in education and training. In industrial practice there are many aspects to a problem to consider; whereas educational practice often explores only one topic at a time. In the Manufacturing Cost Analysis course at SDSU, students explore several topics together as they complete a cost-estimating project involving disassembly and cost analysis of a coffeemaker. The entire nine-part process can also be viewed as an inductive form of learning called the Kolb Cycle, which is defined as a cycle of concrete experience, reflective observation, abstract conceptualism and active experimentation. This paper discusses this nine-part process in detail; how students learn from the process, and how the process can be useful in other engineering and engineering technology learning and training situations.

1. Introduction

Instructors often face considerable challenges when introducing topics in engineering and engineering technology courses. Many of the concepts found in these programs will be utilized in a practical environment where there are many situational factors that influence the application of the concept. These situational factors are often outside the scope of the course. The challenge lies in the method for presenting this type of course material such that students will be better prepared to solve problems in their future professional careers.

One example is the Manufacturing Cost Analysis (MNET 460) course, a senior-level course whose main focus is on cost estimating related to various manufacturing processes and products and developing budget proposals for analysis and evaluation of manufacturing capital expenditure. The course is a Capstone-type course, where students must bring together their learning on many different topics to apply to a project. There are three main learning objectives of the course. First, students must demonstrate their ability to estimate costs for a process and a product introduced in the course. A second objective is to have the student show they can integrate other concepts learned (or not yet learned) elsewhere in the curriculum and articulate their understanding of how various curricular elements overlap and intertwine within the operational environment. The third objective is to have students demonstrate their ability to critically examine the current reality and propose changes that meet certain operational goals, in this case, cost reduction. Developing a cost estimate for analysis and evaluation of a manufacturing capital expenditure is a multi-week project in the course.

2. Educationally Speaking

The approach to this course could be the same as most engineering and technology education courses are taught, using a deductive approach. With the deductive approach, the instructor presents relevant theory and mathematical models, then moves on to textbook exercises, and then, in the case of best teaching practice, to real-world applications. Instructors often pursue what might be called the “Trust Me” approach to education, as in “Trust me—what I’m teaching you may seem pointless now but in another year or perhaps in four years you’ll see why you needed it” [1]. This approach is dominant, and in fact the only way that some students receive their higher education. A better way to motivate students, especially for this course, is through an inductive approach. With inductive teaching, the instructor begins by presenting students with a specific challenge, such as a case study to analyze or a complex real-world problem to solve, and then the instructor lets the students move through the problem in a variety of different ways to find out how to solve the challenge that is posed [2]. Students tend to study hardest and learn best when they are interested in and believe they have a need to know. Studies have shown that relative to students taught in the traditional deductive style, cooperatively taught students tend to have better and longer information retention, higher grades, more highly developed critical thinking and problem-solving skills, more positive attitudes toward the subject and greater motivation to learn it, better interpersonal and communication skills, higher self-esteem, and lower levels of anxiety about academics [1].

Prince and Felder [2] break down the various ways to use inductive teaching into one of six different types. Two different types of inductive teaching are found in the Manufacturing Cost Analysis course. The course uses aspects of both project-based and problem-based learning. Project-based learning involves assignments that call for students to produce something, such as a process or product design. The culmination of the project is normally a written or oral report summarizing what was done and what the outcome was. In problem-based learning, students, usually working in teams, are confronted with an ill-structured open ended real-world problem to solve, and take the lead in defining the problem precisely, figuring out what they know and what they need to determine, and how to proceed to determine it. They formulate and evaluate alternative solutions, select the best one, make a case for it, and evaluate lessons learned.

The manufacturing cost estimate project was adapted from a similar project discovered at another institution long since forgotten. This project starts with a commercially produced coffee maker. The coffee maker is an ideal product for this exercise because it doesn’t require the student to figure out how the product works. The mechanisms involved with heating the water are very simple and do not distract from the real purpose of the exercise, understanding what is involved with analyzing the costs involved in creating the product. In the course of the project, the coffeemaker is disassembled, analyzed, and reassembled. This type of learning activity has been used extensively in Engineering Curricula and has been labeled a Disassemble / Assemble / Analyze (DAA) activity [3]. Within industry, a key purpose of DAA activities is to promote new and better design ideas [4]. An additional reason for using this approach is to help students learn how to be independent learners.

David Kolb has spent many years studying how students learn. As a result of his studies, he writes about what are called the four Kolb Learning Styles [5]. Figure 1 presents these four styles, which he defines as accommodating, diverging, assimilating, and converging.

Kolb suggests that there are definable ways that students approach learning. While some students perceive new information by relying on their senses and immersing themselves in concrete reality, others tend to perceive new information through symbolic representation, analyzing rather than using sensation as a guide. Experiencing the concrete is the opposite of analyzing the abstract. In a similar way, some students transform or process their experience by carefully watching others who are involved in the experience, while others choose to immerse themselves in the experience by doing things. The watchers favor reflective observation, while the doers favor active experimentation [5].

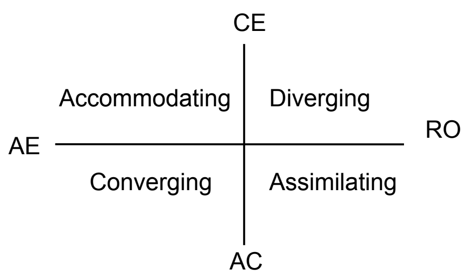

Figure 1. Kolb Learning Styles

Most education theorists think that each student has their own preferred style of learning. Testing of undergraduate engineering students has shown that there are about 10% diverging learners, 40% assimilating, 30% converging, and 20% accommodating learners [6]. Since the students learn in different ways, how should classroom experiences be approached? Sharp, et al., conclude in their studies that instructors should consider three principal objectives for applying the Kolb cycle to engineering education. "As educators, we should strive:

• to reach all our students by teaching to each learning style
• to stretch our students into using all four learning styles
• to teach students to traverse the full learning cycle for themselves, thus becoming independent learners and thinkers" [7].

This philosophy describes the approach used in the cost estimating project for the MNET 460 course. The steps of the project follow what is called the Kolb Learning Cycle. Figure 2 shows this; a simplified form of the previous figure.

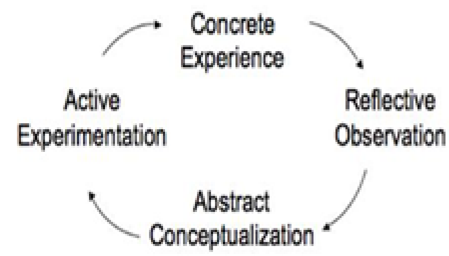

Figure 2. Kolb Cycle

In a well-defined, extensive learning experience that involves some hands-on work, the Kolb Learning Cycle can be defined as follows: "As a learning process, immediate or concrete experiences are the basis for observations and reflections. These reflections are assimilated and distilled into abstract concepts from which new implications for action can be drawn. These implications can be actively tested and serve as guides in creating new experiences" [5]. Over the course of the cost estimate project, the students experience learning activities that take them around this cycle twice, as is detailed below.

3. Method of the Project

The project begins with this problem statement:

One of the most important aspects of consumer product design is manufacturing cost. Because of stiff competition, manufacturers have little control over the selling price of their products. With many products (coffee makers and MP3 players are examples) there is little or

no performance difference between designs. There are only two options to make more profit:
• Add features to justify a rise in price.
• Reduce manufacturing costs.
This assignment will study some of the factors that determine manufacturing costs in a simple product, the electric coffee maker [9].

A good example of how to begin an inductive-based project is to start by posting an open-ended problem. In an inductive–based project there is no initial lecture on the problem. For the cost analysis problem, there was only a problem statement. There were no examples given to the students prior to the assignment and there were no worked problems. There is some structure imposed on the problem, by giving the students an outline of nine parts that they will follow, with each part due in roughly one-week intervals. The nine parts are:

1. Gather all necessary information
2. Analyze the make or buy decision
3. Generate a preliminary manufacturing plan
4. Compute direct materials cost
5. Compute tooling costs
6. Determine manufacturing operation time
7. Determine labor costs and burden rate
8. Comparison of coffee makers, and
9. Generate oral and written reports

First, the students are put into appropriately sized groups, usually two to three students. Each group is given a coffeemaker, and they decide amongst themselves, collaboratively, how they will attack the problem. Students are typically reluctant to participate in team based activities at the start. Experience shows that there is usually some resistance at the beginning of the project. This is a typical response as reported by Prince and Felder [2]. However, students do appreciate the ability to divide up some of the work as it is quite extensive and requires a lot of time. The coffeemakers are all different brands and models so that any collaboration between groups is a sharing of techniques and general information, not an easy way out of doing the work (cheating).

A common difficulty faced by students here is transferring knowledge and skills acquired in other projects and classes to this project, which is in a different subject. As a general aside, the faulty member should include the ability to transfer learning as a student learning outcome of the class, and track how students do on this skill. The faculty should wait for questions to come up, and then answer them fully on facts and sources, but not completely answer all questions. This effort of guiding students to see connections between their current project and what they have learned previously gives them practice in this skill. The faculty should then gradually withdraw this support as the students become more adept at seeing the connections themselves. The instructors should also prepare students to fill in gaps in content knowledge on their own when a need arises, taking into account the fact that such gaps may be more likely to arise in project-based learning than in conventional lecture-based instruction [10].

In Step One, Gather all necessary information, the students are first asked to think about the purpose of the product and develop design specifications. This part of step one fits the definition of the Kolb Cycle Abstract Conceptualization (AC), where the students think about the project, in order to make general concepts more clear to themselves. To develop the design specifications in detail, the student groups must disassemble the product systematically, documenting each step of the disassembly process. This is called a DAA activity, but it is more commonly referred to as reverse engineering.

Reverse engineering is a technique in which a student learns how a particular piece of equipment works by breaking it down into its fundamental parts. If the analysis is successful, the student will understand the purpose of each individual element contained within the system structure. In this way, he or she should be able to construct their own device which performs the same function and includes all of the necessary components [11]. Hess [12] says that this uses the student's natural curiosity, and asks the student to, in essence, think in reverse to learn what the manufacturing process sequence is and what systems of production are used leading up to the finished commercial product.

This is usually the most time intensive part of the project. As a result of this step, the students develop a basic understanding of the steps it takes to assembly the product. This is primarily a preparatory step that allows for more effective learning activities in the next steps of the process, however, they are already developing ideas of how they would improve the product manufacturability. In terms of the Kolb Cycle, the reverse engineering process of project Step One is an Active Experimentation (AE) activity.

Next, the groups develop exploded drawings/sketches of the product and its subassemblies and characterize each individual part found in the product including material type, weight, general dimensions, quantity, and surface finish. A Bill of Materials (BOM) is created for the product. These tasks can be labeled a Kolb Cycle Concrete Experience (CE) task, where they take the information gathered, and make it more concrete for themselves by doing the drawings and making the BOM.

Next is Step Two; the Make or Buy decision. There is not enough time in the semester to design and make the parts that the teams have found are needed. So this step is shortened by deciding that all parts will be purchased for assembly. But the process of making that decision would be a Kolb Cycle Reflective Observation (RO) activity, which is gathering the results of the experiences done so far, weighing the information, and reflecting on what is learned from the process.

In Step Three, Develop a preliminary manufacturing plan, the BOM is separated according to the type of products included in the final assembly. Plastic parts are grouped together, metal stampings are grouped, tubing is grouped, etc. This is done for cost estimating purposes. At the same time, the students are asked to develop a detailed flow chart and/or work instructions for each subassembly and the final product. This often requires the student groups to disassemble and assembly the coffeemaker again to determine the best method for assembly. This step also introduces the concepts of top down assembly, bottom up assembly, and parallel processing in manufacturing, and forces the students to think about the methods and tools required to create the subassemblies. It also stresses the importance of flow charts, one of the seven quality tools [13]. Many of these concepts have been introduced to the students in previous coursework; however, this is perhaps the first time the concepts are presented inductively rather than deductively. The entire step three of the project is a Kolb Cycle AC activity, starting around the cycle again. This AC experience is different than the initial AC activity, thinking about the purpose of the product, but it still requires the students to think about what they will do, in general, abstracting what they have gathered so far, in order to lead into the next stage.

The next two steps of the project are classified as Kolb Cycle AE activities. Again this is different than the initial DAA work that was labeled an AE activity. But these two steps are similar in that they require active involvement, generating new information from the information gathered so far.

Specifically, Step Four, Compute direct materials cost, requires the student groups to calculate the direct material costs for the product. The students do this using the information they generated, and also use pricing tables supplied by the course instructor. Typical loss values are given for the purposes of cost estimation. Students are asked to find pricing on packaging materials and to include their own estimation of loss for these types of materials. This requires them to apply concepts learned in the materials cost estimating portion of the class. Step Five, Compute tool costs, is done next. A supplied standard chart keeps the students focused on the purpose of the project. Steps four and five are where the students usually work the most collaboratively, working together to get appropriate results, rather than breaking the work into separate parts to do individually.

Step Six, Determine the manufacturing operation time, is where the students compute the time it takes to manufacture the product. This requires the students to apply labor estimation techniques learned in the lecture portion of this course as well as to critically examine the process built earlier in the project to determine the best way to efficiently produce product to meet customer demand. Process design strategies are necessary for the students to complete this section. This can be classified as the inductive, problem-based learning portion of the project. The instructor provides a short lecture about theory and instructs the student groups to determine the takt rate (or rate of customer demand) and to determine a process design that will meet takt. Various strategies must be explored by the students to complete this step that are not included in the lectures. Students must learn, on their own, how to improve product flow and meet takt rates while keeping costs low. This problem based learning section results in several approaches to the problem that are informative to the whole group when the results are reported at the end of the project. This learning objective is not a direct learning objective of the course; however, it is important to the outcomes of the entire curriculum. This exercise serves to provide a capstone type learning activity that integrates concepts from across the curriculum. Step six, as well as the following step seven, are Kolb Cycle CE strategies.

Step Seven, Determine the labor costs and burden rates, helps the students to make concrete the work they have just done, in order to bring the entire project together. Once the manufacturing plan is finalized, the student groups can calculate the direct labor and burden for the product based upon the estimations made in the previous steps.

Step Eight, Comparison of coffee makers, is another Kolb Cycle RO activity. The students compare the different coffee makers and the processes used to make them, to determine if there are ways to improve the product by reducing costs. The students are asked to suggest changes and then to estimate how much money they would save by making the change. This requires them to go back and repeat the cost estimation procedures for both labor and materials as well as to critically examine where the best opportunities for improvement occur in the process.

The final activity of the project is Step Nine, Generate oral and written reports. These are also Kolb Cycle RO activities, because preparing the reports requires reflection on the entire project.

Table 1 identifies the nine part process of the project, the work being done in each part, and which part of the Kolb Cycle the students are experiencing in each.

As can be seen, students cycle through the Kolb Cycle twice as they carry out the project. This gives the students an opportunity to stretch themselves from their preferred style of learning. The students often see that other members of the project group are better at different parts of the project, probably because it fits that student's style of learning better. This allows the students to see, in action, that others learn differently. Seeing how others learn differently is another valuable lesson, which they will need to be aware of and use, when they work in industry.

Table 1. Project Steps and Kolb Cycle

Step	Kolb Learning Ability Exercised	
1	Gather information	
	Plan for project	AC
	Disassemble	AE
	Write out BOM Develop drawings	CE
2	Make or buy decision	RO
3	Preliminary manufacturing plan	AC
4	Compute direct materials cost	AE
5	Compute tooling costs	AE
6	Determine manufacturing operation time	CE
7	Determine labor costs	CE
8	Comparison of coffee makers	RO
9	Oral & written reports	RO

4. Assessment of Learning

As a part of the MNET program's ABET-TAC Accreditation assessment process, student learning is assessed during this cost-estimation procedure. Specifically, the program assesses how well students meet Criterion 3, Student Outcome d) Graduates of the program have an ability to apply creativity in the design of systems, components or processes appropriate to program objectives. Over the course of the last three academic years, students have averaged a rating of 9 out of 10 on their learning for this procedure, with 95% of students meeting the goal of a rating of 8 out of 10. The project is evaluated using an extensive rubric covering assembly drawings and design specifications, assembly and flow diagrams, material cost computations, manufacturing time and labor cost analysis, comparison of manufacturability, improvements proposed, and summary and conclusion.

Typical comments about the cost-estimating procedure are:

- Students gain an appreciation of the tools for cost estimation,
- Students have a better understanding of process design, and
- Students enjoy the concept-integrating nature of the project.

5. Conclusion

In the MNET program's Manufacturing Cost Analysis course, the faculty has, over the years, developed a cost estimating procedure that challenges the students through an inductive learning process. The students are presented with a problem to solve, and they must use several types of learning as they work their way through the process, to reach a goal of cost estimating related to various manufacturing processes and products and developing budget proposals for analysis and evaluation of manufacturing capital expenditure.

Can this type of learning be extended to other courses and training opportunities? Faculty who teach to only one Kolb Learning Style, or whose class activities fit only one part of the Kolb Learning Cycle, are likely to reach only some of the students in a given course. The authors of this paper believe that the use of a variety of teaching approaches has the potential to enhance the learning and performance for a wider range of adult students. Teaching in the inductive learning style, that is, begin by presenting students with a specific challenge, and then let the students move through a variety of different ways to find out how to solve the challenge, requires more work for the faculty, but it helps students practice how to become independent learners.

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Spotection: An Efficient and Versatile Parking Spot Detection System

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Abstract

Spotection is a parking spot detection system that will assist in finding parking spaces in a quick and efficient manner by providing users with a graphical representation of a parking lot of interest that highlights which spots are free. A lightweight image processing algorithm is utilized in combination with a video feed of the parking lot to determine which parking spots are free and to eliminate redundant elements. The less-than-optimal camera position is compensated by the utilization of a flexible algorithm that adjusts to various viewing angles and variable lighting settings in real time. Along with the utilization of open source software, Spotection is designed to require minimalistic system resources and setup routines. Lastly, it is also designed to work with inexpensive camera hardware. Overall, this allows for an efficient, easy-to-use, and cost-effective parking spot detection solution.

1. Problem

In today's world, automobiles are everywhere. Within the United States alone in 2010, there were 250,272,812 registered vehicles, which is only about 19% less than the total population of that year [7][9].Because there are so many automobiles in use, parking lots of many businesses, government agencies, schools, universities, and other areas are often congested. This congestion makes it difficult for individuals to find empty parking spaces in which to park their cars, forcing drivers to often waste time searching for an empty spot. The current system of "every man for himself" used for finding parking spots is not only inefficient and, in most cases, is aggravating.

When it comes to the parking congestion problem at colleges and universities, students are forced to look for a free parking spot within the congestion, which often results in tardiness that can negatively affect a student's overall academic experience. In addition to the tardiness, today's inefficient system of parking can also result in illegal parking in reserved parking spots, such as spots for faculty staff, and spots designated for the handicapped, that are closer to the destination than non-reserved spots.

2. Current Solutions

There have been solutions developed for parking spot detection; however, there is no unified algorithm for determining which areas of a parking lot are to be considered as parking spots and which of those spots are free. Some solutions focus on determining which areas of a parking lot are to be considered as parking spots automatically [11]. Although determining the parking spots automatically means less work for the end user, this method can potentially lack dynamics, for in order to automatically determine which areas are to be considered as parking spots, there must be clearly-marked parking lines on the parking lot. There are parking lots, however, with little to no maintenance with parking lines that are too faded for this type of system to detect. Furthermore, this type of algorithm is unlikely to succeed in inclement weather, such as snow, as the parking lines will not be visible to the camera.

Furthermore, whether the parking spots are determined automatically or not, many of the current solutions implement complicated algorithms. One example of this is demonstrated in the study Free Parking Space Detection Using Optical Flow-based Euclidean 3D Reconstruction [8], in which there are ten stages alone for detecting a free parking spot. These ten stages are not simple either. Because there are so many complicated components to this solution, the likelihood of someone's resuming research on this project is low. It is also possible that all of the components to this project are computationally-intensive, requiring a machine with high system specs to operate.

Other current solutions require special hardware; one solution's being the implementation of parking sensors on each parking spot. This solution has previously undergone testing in New York City in January of 2012 [5]. While a small amount of sensors may be considered as inexpensive, when assessing multiple parking spots (an entire parking lot), the accumulated cost can be expensive. Moreover, maintenance costs are incurred, as the more hardware necessary for the job, the more hardware that can potentially wear out or break.

Lastly, many of the current solutions test with cameras that are mounted high above parking lots, yielding a good vantage point for the camera. However, these camera-mounting points used require a dedicated infrastructure, such as when mounting on the side of a building, on a light pole, or most mounting points within a garage. In addition, some of the solutions requiring a dedicated mounting infrastructure require that the camera is viewing the parking spaces in question from a certain angle [2].

3. Spotection Overview

Our parking spot detection solution is called Spotection. Spotection is a cost-effective and easily-configurable parking spot detection solution. It utilizes the C++ programming language along with the Open-Source Computer Vision library (OpenCV) for processing images provided by a webcam video feed of the parking lot to be assessed [6]. Spotection is designed to work with inexpensive webcams with the intention of mounting them within a buildings window or other area for easy mounting. This means that Spotection requires no professional setup, dedicated mounting infrastructure, or wiring is required.

When it comes to the determination of valid parking spots, the user manually determines which areas of the parking lot are to be determined as parking spots, and in doing so, the determination of valid parking spots is less labor-intensive on the system on which Spotection is running, and, more importantly, is dynamic to allow the assessment of any parking lot, including areas with no parking lines at all.

After the user has marked the areas of the parking lot to be considered as spots, the parking lot and parking spot data is stored in a MYSQL database, allowing for multiple instances of Spotection to run simultaneously for the assessment of multiple parking lots. Implementation of the MYSQL database provides convenience as well, allowing the user to start Spotection to assess any parking lot in the database at any given time after setup (MYSQLDOC).

During the assessment of each parking lot, a lightweight image processing algorithm is used to determine which spots are occupied and which spots are not. This algorithm only runs one time after each specified time interval provided by the user (for example, every five or ten seconds). This prevents Spotection from using much system resources. Furthermore, because of the intended mounting locations used with Spotection may not provide the best-possible view of the parking lot for the cameras, the system is designed to account for that. Spotection's utilization of the Canny edge detection methodology helps to remove noise and obstructions from images taken by the webcams allows Spotection to be used from multiple angles in less-than-optimal viewing locations. This works because Spotection focuses on the percentages of edges detected within areas marked as parking spots to determine if a spot is occupied or not. In addition, Spotection automatically adjusts the sensitivity of the Canny edge detection algorithm according to the amount of edges detected, which are relative to the amount of light on the area being captured by the camera [3]. In short, Spotection accounts for changes in lighting settings automatically.

Lastly, after the algorithm has determined which spots are occupied and which are not, the user is presented the results. The user can either be presented with only the number of empty parking spots within a lot (for if the user was to attempt to use Spotection while driving) or with a graphical representation of the parking lot that highlights free spots in green and occupied spots in red (for use after the user has stopped his or her car in a safe area in which to view the graphical representation of the parking lot). This representation is easy for the user to decipher quickly and prevents any violation of privacy, as no vehicles or license plates are displayed on the graphical representation. The results from Spotection, both numerical and graphical, are available to the user via a web application for access on the go.

4. Spotection Setup

To setup a parking lot to be assessed by Spotection, the user is prompted to input the camera device number. If the user does not know the correct camera device number, the user has the option to test all camera devices sequentially (displaying each camera's view to the user) in order to obtain the correct device number. After the user has obtained the correct camera device number, he or she is required to input a name for the parking lot to be assessed. Parking lot names must be unique so there is no overlap, and the parking lot name input is rejected if it already exists in the system. This is because a large parking lot may not be viewable by one single camera, so one parking lot can be divided into four sections (for example, Marshall University Towers Lot A and Towers Lot B).

Next, the user is presented with a live video feed from the camera specified in order to allow the user to position the camera to his or her preference. This is accomplished by using an OpenCV CvCapture object in combination with the cvCaptureFromCAM(dev) function where "dev" is the camera device number [6]. After the user is satisfied with the camera position, he or she will make Spotection take the initial snapshot of the parking lot for marking the areas to be considered parking spots. The snapshot is captured from the video feed by using the cvQueryFrame(cap) function, where "cap" is the name of the CvCapture object [6].

To mark an area as a parking spot, the user must mark the corners of the area in a clock-wise manner starting with the area's upper-left corner. The user, however, is not limited to marking spots that are purely rectangle-shaped. Spotection works with parallelogram-shaped parking spots as well. As long as the user marks the spots in a clock-wise manner, Spotection can assess areas of many different shapes and sizes. Spotection displays the markings the user makes on the image as he or she makes them. After all four corners have been marked, he or she may accept or reject the parking spot as valid.

When the user marks a corner of a parking spot on the image of the parking lot, the x and y coordinates of the of the mouse click are captured using the cvMouseCallback() function [6]. Those captured coordinates are then stored in variables: spotx1 and spoty1 are the coordinates of the upper-left corner point, spotx2 and spoty2 for the upper-right corner point, spotx3 and spoty3 of the lower-right corner point, and spotx4 and spoty4 for the lower-left corner point. After the first two corners have been marked, the x and y coordinates of the midpoint between the first two corners are then calculated and stored as mx1 and my1 using the midpoint formula mx1 = (spotx1 + spotx2)/2, and the same goes for the midpoint y coordinate, my1. The mx1 and my1 coordinates make up the midpoint m1. The midpoints are calculated as each corner of the parking spot is plotted. When the last corner is marked, the midpoints between the third and fourth corner and the fourth and first corner are calculated simultaneously. Next, the center point of the parking spot is calculated by calculating the midpoint between the midpoints of the parking spot. The following formula is used for calculating the x coordinate of the spot's center point: cx = (((mx1 + mx2)/2) + ((mx3 + mx4)/2) /2. The same calculation is done for computing the y coordinate of the spot's center point, substituting all of the "mx" variables with all four "my" variables. After the center point calculation is complete, the x and y coordinates of the center point of the parking spot are stored a cx and cy. Figure 1 is a diagram of a fully marked parking spot.

When an entire spot has been marked and the user has accepted the markings as a correctly-marked parking spot, all of the x and y coordinates that were captured and calculated are stored in a spot struct. A struct is simply a data structure that unifies several variables, which can be of the same or different data types, under a single entity, much like an object does in object-oriented programming ([4]). Each spot struct holds a spotID along with all of the other

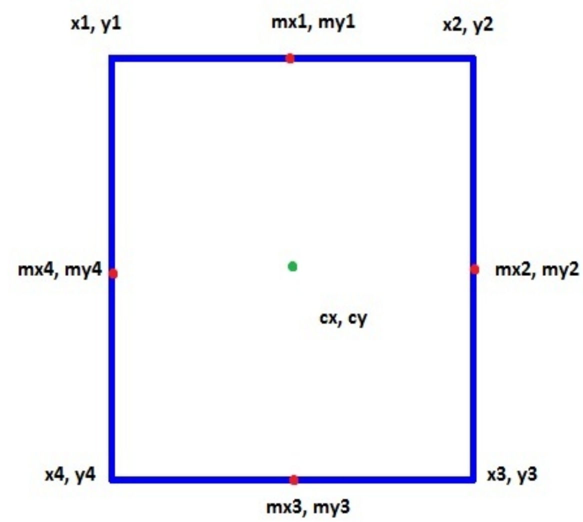

Figure1. Marked Parking Spot

points that were captured and calculated. To hold all of the parking spots, we use a vector. A vector is a sequence container which holds multiple items of the same datatype, which is declared at instantiation of the vector [10]. In our case, the vector is of the spot struct data type we use to hold all of the spot coordinates. As each spot is marked and accepted as valid, the spot struct holding the spot coordinates is added to the spot struct vector, after which the coordinates are stored in the database. The main reasons we use a vector are that items within a vector can be accessed by an index (the location of the item within the vector), and loading the spot coordinates into the vector of spot structs at startup means the database is only accessed once during runtime [10].

5. Spotection Database

Spotection uses a MYSQL database to store all of the parking lot and parking spot data gathered from the setup phase. The database uses two tables. The first table is called "parkinglots" which has two attributes, an integer called idParkingLots, the primary key and ID of each parking lot, and the name of the parking lot (varchar(45) type), Name that has a unique constraint on it, preventing duplicate parking lot names in the database. The second table is called “spots”, which holds all of the parking spot information. All of the attributes in this table are integers, and there is an attribute in this table for each x and y point necessary to define a parking spot, including the x and y coordinates for each corner point, each midpoint between each corner point, and the center point for each spot. Its primary key is idspots, which auto-increments. Its foreign key is idParkingLot, which is the parking lot ID for the lot to which the spot belongs. This schema allows for the user to simply input a parking lot name, and the system retrieves all of the spots associated with the given parking lot by the parking lot ID. Also, there is a delete cascade on idParkingLot attribute, so when a parking lot is deleted from the parkinglots table, all of the spots associated with that parking lot in the spots table are deleted automatically by the database.

The user is presented with options to assess a parking lot that is already in the system, check for existing parking lot names, and delete an existing parking lot from the system. Assessing a parking lot that is already in the system and deleting a parking lot from the system are done by providing the parking lot name. As a result, the user does not need to know anything about the parking lot IDs, as Spotection performs the queries for retrieving the parking lot ID by name and proceeds to retrieve the parking spot information by parking lot ID. After the spot information is retrieved, all of the information is stored in a vector of spot structs described in the last section. All this was made possible by using the MYSQL C++ connectors in combination with MYSQL server [1].

6. Image Pre-Processing and Automatic Lighting Adjustment

When Spotection assesses a parking lot, it takes a snapshot of the video. Spotection then processes the snapshot using an image processing algorithm that is built into OpenCV, cvCanny(), which uses the Canny methodology for edge detection [6]. The Canny edge-detection methodology seems to be considered as the standard for edge detection, hence why there is a function for it built into OpenCV. The edge detection algorithm takes in an image, then detects the edges within the image, and returns an image that is nothing but black and white (Fig 2) where white pixels are edges.

Figure 2. Snapshot before and after being processed with edge detection

The edge detection algorithm takes in several parameters, two of which are threshold parameters: a high threshold and a low threshold. These threshold parameters adjust the sensitivity of the edge detection algorithm: the higher the thresholds, the less noise (things detected as edges) in the image that is returned. These thresholds are critical for Spotection because if the thresholds are too high, many of the edges of the cars are ignored, meaning it is impossible for Spotection to tell if there is a car in a spot or not. If the thresholds are too low, most of the picture will be white, meaning that the cars will blend in with all of the other detected edges. Overall, the high threshold adjusts the sensitivity of the edge detection algorithm more radically, while the low threshold adjusts the sensitivity less than the high threshold does, allowing for the adjustment of the sensitivity to a finer specification [3].

In order to correctly set the thresholds for the edge detection algorithm, Spotection bases them off the percentage of white pixels in processed image that is returned. After testing, the best target percentage for the white pixels in the processed image to be assessed is about 4%. For the first snapshot taken upon using Spotection, the high threshold, highThresh, and the low threshold, lowThresh, are both set to zero.

The target percent is set to 4% by default, but the user is able to set the target threshold for the edge detection on the fly by changing the position of a trackbar on the Spotection GUI. This gives the user complete control of the automatic threshold calculation, allowing the user to lower and raise the sensitivity. The user can lower the sensitivity (by increasing the target percent with the trackbar) to the point at which the automatic threshold calculation feature is virtually turned off.

The automatic calibration for the edge detection is also used to accommodate for changes in lighting throughout the day. For example, if it is a very sunny day, and later in the day, it becomes cloudy, Spotection re-adjusts the thresholds based on the change in the percentage of white pixels since the last time the thresholds were calculated and the percentage of white pixels in the current snapshot. This is because changes in lighting settings in the area being captured by the webcam have a significant effect on the output of the edge detection function.

Checking the white percentage change is done each time Spotection takes a snaphot. However, the automatic calculation of the thresholds can be labor intensive on the system, so it is only done if there is a significant change in the percentage of white pixels in the current snapshot compared to the percentage of white pixels from when the edge detection thresholds were last calculated, which is the targetChange. The sensitivity of this algorithm is based on the value of targetChange, which can be changed by the user on the fly by changing the value on a trackbar on the Spotection GUI.

7. Empty Spot Detection Algorithm

In order to detect which spots are occupied and which ones are not, Spotection first retrieves all of the parking spot information from the MYSQL database based on the parking lot name provided by the user after he or she is prompted for the lot name. The spot information is then stored in a vector (sequence container that holds multiple object/variables of the same datatype) of spot structs (data structure holding all of the parking spot coordinates) to be used when detecting which spots are occupied and which spots are not [4][10].

Next, Spotection takes a snapshot from the video feed of the parking lot after each specified time interval (for example, every five or ten seconds) has passed. After the snapshot is taken, it is processed with the cvCanny edge detection function described in section 6 of this paper [6]. Then Spotection checks to see if the edge detection thresholds need to be updated using the checkWhitePercentageChange algorithm also described in section 6, and if the thresholds are updated, the snapshot is re-processed with the updated edge detection thresholds.

After the snapshot of the parking lot is processed accordingly, the first parking spot in the vector of spot structs is retrieved. Using the coordinates of the upper-left corner of the parking spot, the region of the snapshot corresponding to the parking spot is set as the snapshot's region of interest using the cvSetImageROI function. The upper-left corner is used because OpenCV only cuts images based on rectangles in which the origin of the rectangle (the upper-left corner) is given, proceeding with the height (the difference between the x coordinate of the lower-right corner and the x coordinate of the upper-left corner) and width (the difference between the y coordinate of the lower-right corner and the y coordinate of the upper-left corner) of the rectangle [6]. After the region of interest is set, it is copied into another image, after which the original snapshot is reset. This basically cuts the area of the parking spot out of the snapshot so it can be assessed.

After the parking spot is cut from the snapshot, all of the points of the parking spot are used divide the parking spot into four separate quadrants to be assessed. This is accomplished by using the cvSetImageROI function by providing it the parameters of the rectangle-shaped region of interest, which are the coordinates of the upper-left corner, the width, and the height of the region of the picture that is to be cut. Then, the region of interest set by the cvSetImageROI function can be cut from the image. [6]. Figure 6 shows the parking spot coordinates in corresponds to which quadrant on the image of the parking spot. Each quadrant of the parking spot is a separate region of interest.

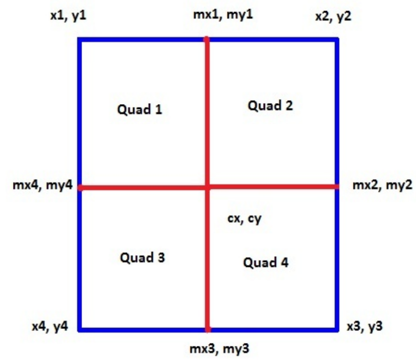

Figure 3. Parking Spot Quadrants

The image of the parking spot has already been processed through the edge detection algorithm, so each individual quadrant of the parking spot can now be assessed. To assess the first quadrant, it is first cut from the image of the parking spot using the method described above. Then the number of white pixels in the quadrant is calculated by using the cvCountNonZero() function [6]. Next, the percentage of white pixels in the quadrant is calculated by dividing the number of white pixels in the quadrant by its area. If the percentage of white pixels in the quadrant is greater than the user-specified threshold (set on the fly by changing the position of a trackbar on the Spotection results window), the quadrant is considered as full, and the next quadrant is assessed, and if the percentage of white pixels in the quadrant is less than the specified threshold, the quadrant is considered empty, which means the spot is considered empty. All four quadrants must be considered full for the parking spot to be considered full. This approach is used for detecting false positives (such as when a car is not in a parking spot but is parked in such a way that the camera sees said car as being in the parking spot), which plays a big role in Spotection's accounting for less-than-optimal viewing locations. Figures four through six provides an illustration of the detection process.

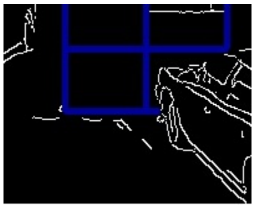
Figure 4. Two quadrants completely empty. Spot not occupied

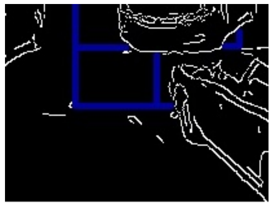
Figure 5. One quadrant completely empty. Spot not occupied

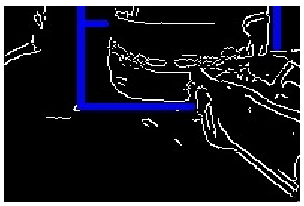
Figure 6. Most of each quadrant is occupied. Spot is occupied

8. Conclusion and Future Work

The most important functionality to be added to Spotection is the end user interface that will allow the user to view which parking spots are free via a web browser. This web front end plays off the increasing number of smart phone users, so when a patron arrives at a parking spot, he or she will be able to take out his or her smart phone, navigate to the web front end, look up the appropriate parking lot on the website and get the results. Simplicity is key for this display so the user may pick and locate a parking spot with ease, preventing visual details such as cars themselves and anything else from getting in the way of the user's ability to make his or her decision quickly. Other attributes that can be added to Spotection are the special cases: A large cardboard box that covers much of the spot may be considered as full. The detection of motorcycles and ATVs, and the detection of vehicles that are double-parked.

Another feature that could gain the interest in Spotection of many is obtaining statistics from continuous use of Spotection. One possibility of implementing this feature is reporting to businesses how often their parking lots are full and/or which spots are full the most. It will help businesses make decisions on whether to add more parking lots for their customers. It also allows for law enforcement by reporting when a car has been parked on a no parking zone.

In conclusion, Spotection is a framework for lightweight, easily-configurable, and cost-effective parking spot detection. It is cost-effective because it was designed to use minimalistic system resources and work with inexpensive camera hardware with no professional mounting or wiring. In addition, all of the software components are open-source, so there is no cost for the software to the user.

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A Study of Dimensional Accuracy in Abrasive Waterjet Machining

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Abstract

At the National Institute for Aviation Research, composite panels are machined into specimens and tested to verify their mechanical properties. With the recent introduction of Abrasive Waterjet machining into the specimen preparation process, the goal of this research is to increase the productivity of the machine while meeting dimensional accuracy requirements. A statistically designed experiment was performed to quantify the effect of selected process variables on the dimensional accuracy of composite specimens. Numerical optimization was used to determine appropriate settings that help improve performance levels.

1. Introduction

Composite materials are being utilized in different fields from aerospace to healthcare. As the name implies, composites are made of two or more materials combined together for the purpose of producing a single material possessing properties that are superior to its individual ingredients. The attractiveness of composites stems from the superiority of several of its properties. Its high specific tensile strength, high specific modulus, and toughness encourage the exploration of their use in areas of application where weight reduction (e.g., Aviation and Aerospace vehicles) is of special importance. The tolerability and flexibility of designing composites to serve a particular purpose make them more attractive than materials with predetermined directional properties such as metals. Their minimal response to temperature variation makes composites ideal candidates for use in high tech applications such as satellites and circuit boards.

Machining of composites differs from regular metal machining because the fibers in the composite material require a tool with high resistance to abrasion. Komanduri (1997) provided a broad overview of the various issues involved in machining fiber-reinforced composites. Composite materials can be trimmed and cut utilizing conventional metal cutting processes with modified settings (speed, feed, and depth of cut) as well as cutting tools. In most cases, the cutting speed should be increased and the feed rate decreased relative to normal levels used in metal cutting. Cooling is necessary to prevent build-up on the cutting tool and overheating of the part. However, studies reported by Qin et al., (2008) have shown that when the diamond-coated tools wear out or delaminate, cutting forces increase sharply. These forces can not only destroy the tool but damage the structural integrity of the composite part.

Abrasive Waterjet (AWJ) cutting has gained wide support as a method to machine composites. AWJ uses water and abrasive material at high velocity and pressure to cut through composites. As was pointed out by Strong (2008), the erosion process produces less cutting forces than most traditional cutting methods with no noticeable heat-affected zone in the vicinity of the cut. In addition, it requires clamping to support the part only, minimizing the risk of delamination and edge damage of the parts.

At the National Institute for Aviation Research (NIAR), composite panels are machined into specimens and tested to verify their mechanical properties. This research was motivated by the recent introduction of Waterjet machining into the specimen preparation process. The research is aimed at quantifying the effect of changes in the process parameters on dimensional accuracy of the machined specimens as well as identifying appropriate settings that yield target performance levels. The following section represents relevant background of the process and cited research characterizing its performance. This is followed by a representation of the experimental study performed and the results obtained.

2. Background

Waterjet uses a jet of filtered water utilizing an intensifier pump to pressurize water up to 55,000 psi and force it through a nozzle of small diameter (0.01”- 0.07”) onto the part. Just like any machining process, waterjet cutting is subject to variation in its results. The total variability can be attributed to numerous factors. Earlier research on the process performance focused on the effect of adding abrasives to increase the cutting capability. In a study by Colligan (1993), when no abrasive was used in the waterjet, the surface finish exceeded the limit of the surface analyzer of 25µm. In a drilling experiment by Krajca and Ramulu (2001) the lack of abrasive at the highest pressure setting created a complete loss of structural integrity of the laminate.

When an abrasive is added, AWJ is especially useful in cutting a wide range of advanced composites. Colligan (1993) performed a study to evaluate effects of jet feed rate, abrasive flow rate, and laminate thickness on various aspects of striations and surface roughness. He noted that at the low feed and high abrasive flow rates, striations are parallel to the jet path through the laminate cross-section. Large abrasive flow rates appear to reduce both the magnitude and frequency of striations.

Performance of AWJ and diamond machining of composites, were compared by Hashish (1995). He indicated that AWJ cutting is about 20 times faster than diamond cutting, but surfaces are generally 10 times rougher. In a process which requires turning, AWJ improved volume removal rate and reduced machining time by over 50%. The removal rate for hard-to-machine materials was shown to be over 10 times greater than that of solid tools. In addition, he noted the relationship between the fiber and jet diameters and their effect on jet deflection. Unlike traditional cutting processes, AWJ machining does not subject the part to thermal deformations or mechanical stresses. The process is dust-free, odorless and can cut complex patterns. On the other hand, noise levels and the need to monitor water filtration are typical concerns. However, the literature offers qualitative knowledge of limited value to practitioners and machine owners. Such knowledge cannot be extrapolated to model performance under varying machine and process variables. In order to fully realize the benefits offered by an AWJ machine, experimental studies aimed at quantifying the effect of changing levels of the machine and process variables are needed. The procedure presented in the remaining sections of this paper can be followed in gaining better understanding of the process and its variables.

3. Experimental Study

A variety of tests are performed at NIAR. Typically composite laminates are made in large panels, and then cut into smaller specimens as required by the customers or standard test procedures. The machine shop handles a wide range of customized panels with varying configurations and thicknesses. Milling machines, equipped with diamond-coated cutting tools with continuous cooling, were used to cut composite specimens. In order to achieve target dimensional tolerances, the milling operations were performed at a feed rate of only 2 inches per minute (in/m). This is the first step in the specimen preparation process and having such slow rate reduces productivity of the entire testing process.

Recently, these milling machines were replaced with an abrasive waterjet (AWJ) machine which enables the machine shop to cut composite panels at much higher rates of up to 10 in/m. The AWJ is equipped with a computer controlled servo mechanism which controls the cutting head. The accuracy of the cutting nozzle and servo is $\pm$0.010" with repeatability of $\pm$0.007" over a span of 4 feet as asserted by the equipment manufacturer. The WaterjetPro (Figure 1) uses a PC based software to control the servo mechanism (PA 8000 CNC). The machine utilizes high performance garnet (HPX by Barton International, NY) as the abrasive material with an average particle size of 120 grit.

Figure 1: The Waterjet Pro (50" x 50" x 8").

3.1. Experimental factors

The objective of this study was to evaluate the effect of selected process factors on the dimensional accuracy of the test specimens. These included the feed rate (A), water pressure (B) and the standoff distance (C) between the head and the specimens. Two levels were assigned to each factor as shown in Table 1.

These levels were selected to assure penetration through the material and avoid jet deflection. A special NC program was prepared to cut tabs holding the 0.5" by 1" specimens together. Other process variables that were not evaluated in this study are considered as held-constant factors. The experiments were performed in a randomized order to protect against nuisance factors e.g., material variability and changes in environmental conditions.

Table 1: Experimental factors and their levels

	Units	Low	Nominal	High
Feed Rate (A)	in/m	50	75	100
Water Pressure (B)	10^3 psi	30	40	50
Standoff Distance (C)	in	0.05	0.10	0.15

3.2. Response variables

The workpiece material used for this experiment was a Cycom 5320 T659–3K–8HS prepreg panel with an average thickness of 0.12". The specimens for the experiment were cut to 0.5" by 1.0". Deviations from the target width of 0.5" were measured at 3 locations using a Mitutoyo Absolute IP67 digital caliper with reported accuracy of 0.001" and resolution of 0.0005". The measuring range for the caliper is 0-6" with repeatability of 0.0005".

The process performance was characterized in terms of two response variables. The first represents machining accuracy measured in terms of the average deviation from the nominal width. Whereas, the second represents machining precision measured in terms of the standard deviation of repeated measurements.

3.3. Experimental design

A factorial design was utilized involving the three selected factors, each tested at two levels (i.e., 2^3 factorial design). The experiment was repeated twice with four center points added to detect curvature. The addition of center points was facilitated by the fact that the three design factors are quantitative. This type of design can be easily augmented into a response surface (second-order) design based on an indication of significant curvature. Myers et al (2009) provide an excellent guide for the sequential applications of such designs. The design matrix including a total of 20 runs with the corresponding values of the response variables is shown in Table 2. Experimental units were cut and measured in a randomized order.

4. Data analysis

Statistical analyses of observed data were performed utilizing the Design Expert, version 7.1 (Stat-Ease, 2007). The procedure used follows closely that given by Montgomery (2009). First, the analysis of variance is used to indicate the significance of curvature and model aptness. Indications of significant curvature and lack of fit would require the deployment of a second order design (e.g., central composite, or Box-Behnken design). This is typically achieved

Table 2: Design matrix and response variables

Std	Run	(A) Feed Rate (in/m)	(B) Water Pressure 10^3 (psi)	(C) Standoff Distance (in)	Average Deviation (in)	Standard Deviation (in)
7	1	100	50	0.05	0.002	0.0035
11	2	100	30	0.15	-0.005	0.0060
12	3	100	30	0.15	-0.006	0.0060
3	4	100	30	0.05	-0.006	0.0055
20	5	75	40	0.1	-0.002	0.0030
16	6	100	50	0.15	-0.001	0.0040
14	7	50	50	0.15	-0.002	0.0020
2	8	50	30	0.05	0.002	0.0030
19	9	75	40	0.1	-0.003	0.0035
15	10	100	50	0.15	0.001	0.0035
5	11	50	50	0.05	-0.005	0.0015
4	12	100	30	0.05	-0.008	0.0050
1	13	50	30	0.05	-0.001	0.0030
17	14	75	40	0.1	-0.002	0.0040
13	15	50	50	0.15	-0.001	0.0020
8	16	100	50	0.05	0.002	0.0035
18	17	75	40	0.1	-0.001	0.0030
10	18	50	30	0.15	-0.001	0.0025
9	19	50	30	0.15	0.001	0.0030
6	20	50	50	0.05	0.0005	0.0020

by combining the design in Table 2 with axial or star runs in a second block. Otherwise, regression methods are used to develop first-order response surfaces characterizing the process performance. Second, resulting surfaces are used to recommend settings of the experimental factors at which target levels of performance could be achieved. Finally, additional runs are performed to verify the results. The following two sections summarize results of the analysis of each response variable.

4.1. Accuracy assessment

Table 3 represents results of the analysis of variance (ANOVA) for the average deviation from the target width. As can be seen, the curvature term is not significant, whereas the interaction involving the feed rate (A) and water pressure (B) is significant. The stand-off distance (C) is not significant and was excluded from the model. The lack of fit test indicates, with a p-value of 0.62, that the variation of data around the fitted model is not significant. The resulting regression model representing the average deviation can be expressed as:

$$\text{Average} = 0.024 - 4.1125\text{x}10^{-4}\ A - 5.75\text{x}10^{-4}\ B + 9.375\text{x}10^{-6}\ AB \quad (1)$$

Diagnostic examination of the model residuals revealed no violations of the underlying assumptions regarding the experimental error variance. Overall, the reduced regression model in Equation (1) is significant with p-value of less than 0.0001. Reported values of the predicted R-squared (0.61) and the adjusted R-squared (0.73) are in reasonable agreement with each other, raising no concern with the data or the fitted model. A three dimensional (3D) representation of the fitted model is shown in Figure 2. The strong effect of the two factor interaction involving both factors A and B is indicated by the sharp twist in the fitted surface. An examination of the plot reveals that changes in water pressure have much higher effect on the average deviation at the high levels of feed rate. The maximum average deviation is observed when the high level of feed rate is used with the low level of water pressure.

Table 3: ANOVA for accuracy assessment

Source	Sum of Squares	df	Mean Square	F Value	P-value
Feed Rate (A)	1.31406E-5	1	1.31406E-5	5.523205	0.0329
Water Pressure (B)	2.62656E-5	1	2.62656E-5	11.03984	0.0046
AB	8.78906E-5	1	8.78906E-5	36.94177	< 0.0001
Curvature	2.53125E-7	1	2.53125E-7	0.106392	0.7488
Residual	3.56875E-5	15	2.37917E-6		
Lack of Fit	7.0625E-6	4	1.76563E-6	0.678493	0.6210
Pure Error	0.000028625	11	2.60227E-6		
Total	0.000163238	19			

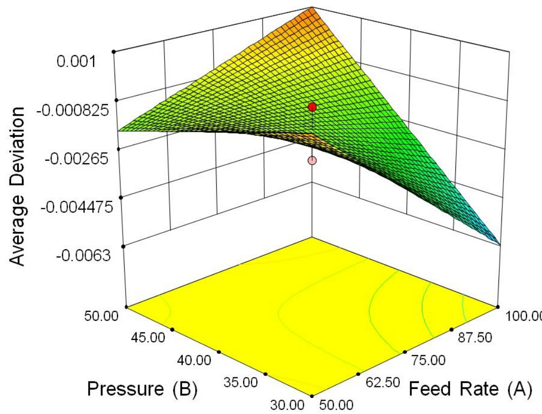

Figure 2: Response surface plot based on Equation (1)

4.2. Precision assessment

Table 4 represents results of the analysis of variance for the standard deviation of repeated measurements. Once again, the curvature term is not significant. Factors A, B and AB are identified as the significant model terms. Factor C does not appear to have a significant effect and was hence excluded. The lack of fit test indicates, with a p-value of 0.21, that the variation of data around the reduced model is not significant.

The resulting regression model representing the standard deviation is given by:

$$\text{Standard Deviation} = 1.25\text{x}10^{-4} + 8.5\text{x}10^{-5} A + 4.54257\text{x}10^{-19} B - 1.0\text{x}10^{-6} AB \quad (2)$$

Diagnostic examination of the model residuals revealed no violations of the underlying assumptions regarding the error variance. Overall, the reduced regression model in Equation (2) is significant with reported p-value of less than 0.0001. Reported values of the adjusted R-squared (0.92) and the predicted R-squared (0.89) are in reasonable agreement with each other. Figure 3 represents the 3D surface generated. As illustrated, the average standard deviation appears more sensitive to changes in the water pressure when the high feed rate is used. The minimum average value is observed at the low level of feed rate and high level of water pressure.

Table 4: ANOVA for precision assessment

Source	Sum of Squares	df	Mean Square	F Value	p-value
Feed Rate (A)	0.00002025	1	2.0250E-5	156.7742	< 0.0001
Water Pressure (B)	0.000009	1	9.0000E-6	69.6774	< 0.0001
AB	1E-06	1	1.0000E-6	7.7419	0.0139
Curvature	5E-08	1	5.0000E-8	0.3871	0.5432
Residual	1.9375E-6	15	1.2917E-7		
Lack of Fit	0.00000075	4	1.8750E-7	1.7368	0.2119
Pure Error	1.1875E-6	11	1.0795E-7		
Total	3.22375E-5	19			

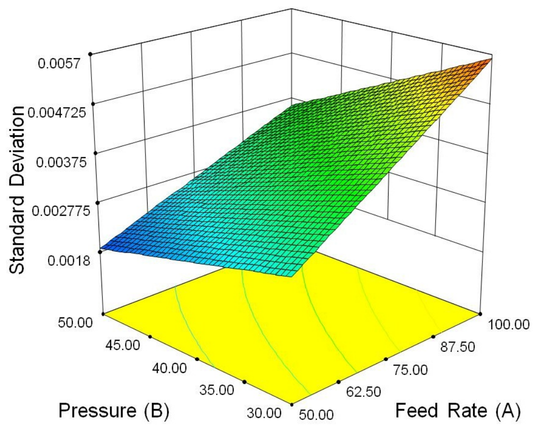

Figure 3: Response surface plot based on Equation (2)

5. Empirical optimization

Based on Equations (1) and (2), an attempt was made to identify operating conditions (settings of the experimental factors) that would optimize the process performance. This required simultaneous consideration of the effect of the feed rate and water pressure on both accuracy and precision of the resulting specimens.

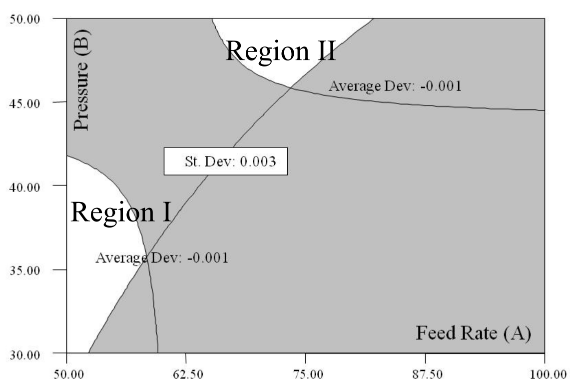

Figure 4: Overlay Plot

The Design Expert software offers constrained numerical solutions using direct search algorithm. These solutions were constrained by the range of experimental factors with the goal of minimizing both the average deviation from target and standard deviation of repeated measurements. Limits of $\pm$ 0.001” were specified for the average deviation with 0.003” as an upper limit of the standard deviation. The resulting overlay plot is shown in Figure 4. The un-shaded portions of the plot indicate a number of combinations of feed rate (A) and water pressure (B) that would result in the target levels of performance. It is important to note that the plot suggests two distinct operability regions. Region II, while meeting accuracy and precision targets, allows much higher feed rates to be used than that of Region I. However, this would require operation at a higher water pressure range which increases the risk of pump and filtration system failure. Consequently, it was decided to operate within Region I using water pressure of 35,000 psi with feed rate of 50 in/min. In order to validate this numerical solution, three additional specimens were cut from the same test panel while maintaining a standoff distance of 0.10”. Table 5 shows expected values of the response variables.

The observed averages were well within the 95% confidence interval (CI), and the proposed settings were adopted for future machining of the material.

Table 5 Results of validation runs

Response	Prediction	95% CI	
		low	high
Average	-0.00028	-0.00153	0.00096
Standard Dev	0.002625	0.002335	0.002915

6. Conclusions

This research was aimed at evaluating performance of the AWJ process used to prepare composite specimens for mechanical testing. Currently, cutting is performed at water pressure of 35,000 psi and feed rate of 10 in/m. It was desirable to increase productivity by operating at higher feed rate. A replicated 2^3 design with center points was utilized as a first step in applying response surface methods. The analyses indicated that first-order models provided adequate characterization of the process performance. Numerical optimization suggested operability regions at which target accuracy levels could be achieved while operating five times faster than the formerly utilized feed rate. While these results are process specific, the methodology employed in this research can be readily applied when machining different material. Additional experiments are underway to quantify the effect of increasing the abrasive flow rate on the resulting edge quality. This may allow for additional productivity improvement by eliminating the need for secondary finishing operations

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Lean Sustainability Assessment Framework (LSAF) for Healthcare Organizations

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Abstract

Lean has started to be adopted by several healthcare organizations at the beginning of the new millennium. This adoption came as a result of the positive impact of lean on the performance of firms belonging to diverse industries. However, the adoption rate within healthcare industry appeared to be slower than it should be and has been accompanied with major challenges. These challenges are related to proper lean implementation, sustainability of achieved levels of performance, and staff engagement in infinite cycles of continuous improvement towards perfection.

In this paper, a framework has been developed to help healthcare organizations quantify their experience with lean. Such quantification is obtained by measuring the agreement level of hospital staff members about the degree of adopting two sets of critical factors of successful lean implementation within their hospitals. The two sets of factors are classified as process factors and organizational factors and they are assessed by the developed framework in a balanced manner.

In order to accommodate for the observed variation in lean adoption in hospitals, individual hospital departments are considered the "analysis units" of the developed framework. The quantification process of lean adoption efforts within a hospital department is obtained by using a survey-based lean sustainability assessment tool developed based on the defined sets of factors. The sustainability level of lean implementation of a hospital is obtained by combining various responses of its surveyed departments.

1. Introduction

Despite their variation in magnitude from one country to the other, healthcare expenditures are remarkably increasing worldwide. Once this increase goes beyond realistic levels, it will jeopardize the quality of care provided by healthcare institutes. One of the tactics that are used to put some control on hospitals' operational expenses is the implementation of effective quality initiatives utilized successfully by firms in manufacturing industry. In these firms, objectives like decreasing process defects, reducing process cycle time, and increasing resource utilization have been amazingly achieved by following one of the quality initiatives named lean. Such achievements have encouraged several healthcare institutes, worldwide, to adopt lean within their organizational setup. However, levels of lean implementation within these institutes represent a wide spectrum with a common challenge of achieving higher levels of sustainability. Therefore, the objective of this study is to develop a framework for assessing the sustainability of lean implementation in organizations within the healthcare industry. The developed framework provides a balanced assessment of two sets of factors essential for achieving sustainable levels of lean implementation. These sets of factors are classified as process factors and organizational factors.

Due to the observed variation in level of lean implementation in hospitals, the "analysis units" of the developed framework is hospital departments. In order to assess the implementation status of lean across various departments in a hospital, a survey instrument has been developed based on nine critical success factors identified from the literature. The sustainability level of lean implementation of a hospital can be obtained by combining different responses of its surveyed departments. Provided that the same group of departments has been surveyed in more than one hospital, the sustainability level of lean implementation in these hospitals can be compared by using the developed framework.

The remaining part of this paper provides an overview about lean concept, lean applications in healthcare, and lean assessment tools available in literature. This will be followed by an illustration of the developed framework together with the assessment tool. Finally, the paper will be concluded with framework validation and summary of related findings and future work.

2. Literature Review

By developing and implementing what is known today as the Toyota Production System (TPS), Toyota was able to turn its 1950s near bankruptcy firm into a global company leading the automobile industry [1]. Their solid growth, resulting from applying their system to various production activities, has attracted a wide spectrum of academic and business audience from outside the auto-industry. As a result, TPS, also known as lean system, has been adopted by many manufacturing and service organizations.

However, not all adopting organizations gained similar results as Toyota did. This is due to the fact of adopting lean tools without understanding the core concepts around which the whole system originally was built [1], [2]. In order to help such organizations get the best out of their experience with lean, significant efforts have been made, by researchers, to study the set of factors that lead to a sustainable level of implementing lean so that levels of performance and cost savings similar to those witnessed in Toyota can be generated. Some of these efforts were focused on developing assessment tools by using which lean adopting firms can know how much lean they are, according to a defined set of critical success factors, while other efforts were focused on defining various levels of maturity which could be observed in a lean adopting organization. However, most of these efforts are performed and/ or geared towards lean implementation setups in the manufacturing sector while few consider both manufacturing and service sectors. Among those service sectors which started to adopt lean and attracted researchers' attention over the last decade is healthcare. This section of the paper covers aspects related to lean development and definition, lean assessment tools, lean maturity stages, and lean applications in healthcare.

2.1. Lean concept

The concept of lean has been developed in the automobile manufacturing field and got spread within and outside that segment of global industry. Toyota is the pioneer company at which this concept has been developed. Thus, it is known as Toyota Production System (TPS). As a response to technological, financial, and labor challenges which Toyota was encountering in 1950s, it was able, over three decades, to develop a new concept for producing automobiles that superseded production systems used at that time, in both yield and quality, while consuming fewer resources and reducing manufacturing lead times [2].

It is greatly interesting to notice that most of lean tools and concepts were developed much earlier than 1950's [2]–[4]. However, it was Ohno's wisdom and other Toyota members which had put the several pieces of the lean system puzzle into their correct places and developed this effective production system [4]. The response of Ohno to a question about "what Toyota is doing now?" lays down the foundation of the whole system. His answer simply was "all we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect cash. And we are reducing that time line by reducing the non-value-added wastes." [5, p. ix] By doing so while enforcing the "respect for humanity" concept at all levels of the organization, Toyota was brilliantly able to create a teamwork-based organization with a primary focus on continuous improvement [2], [5].

As it took Ohno thirty years to reach a mature stage of the system he developed, it can be easily realized that TPS or lean is a *do*, a path towards perfection driven with one simple question: what is the need? [2] Due to the fact of having more than one correct answer, there would be more than one path to meet the defined need [2]. Thus, a precise definition of lean system may not exist [2], [5]. However, several lean definitions are available in literature. See for instance [1], [2], and [6]–[9]. All definitions stated in these references are common in describing lean as a way of using all available resources (i.e. man, machine, material, space, and time) in their minimum possible levels to satisfactorily fulfill customer defined needs; with the objective of decreasing these levels while pursuing perfection through continuous improvement. The definition of Chalice of TPS as "an improvement philosophy or framework that is implemented around a problem-solving methodology" [1, p. 70] gives the adopting organizations the freedom in selecting the framework and the methodology which suit them the most. However, "what's most important is not the particular improvement philosophy and problem-solving methodology selected but rather the simple containment of the organization to demonstrably pursue continuous cost and quality-improvement as part of its ongoing mission and value." [1, p. 70]

Due to the difficulty that has been proven about grasping the lean system as a whole, many lean applications, outside Toyota, tend to be for some of the activities only and that is the reason behind the failure witnessed in achieving the expected results of improvement. In order to gain maximum benefits from applying lean, it is important to know the main principles on which this system is built in addition to understanding the relationship between different lean activities and these principles [2]. Dennis provided a detailed illustration about lean major principles and their related activities based on the house of lean production system [2]. In this house, stability and standardization are the foundation, just-in-time (JIT) and jidoka, or autonomation, are the walls or pillars, involvement is the heart, and customer focus, which is the goal of the system, is the roof. The secret behind Toyota success with lean resides in the continuous reinforcement of system's core principles while understanding the interconnection relationship among their various activities. Lean culture stems from considering the lean production as a *do* or path towards perfection. Such consideration develops the intensity required to encourage effective teamwork and active team members involvement through sharing common understanding, provided by visual management techniques, towards answering the question of "How can we do things better?" in a scientific-based setup by using PDCA cycle as a core management model for the whole organization [2]. However, in order to assure achieving remarkable outcomes, an equal team member's involvement and respect must be encouraged [2]. Thus, it is hard, though achievable; to embrace lean principles completely unless implementing organizations develop the characteristics necessary for successful lean implementation [2].

Understanding Toyota's success while implementing its lean system can be much easier if the paradox behind the observed success is realized. Spear and Bowen state that the main reason behind this giant automaker creativity and flexibility is the rigid specification of everything performed at each manufacturing process [10]. By having built-in mechanisms to signal problems automatically and responding to the revealed problems continuously, Toyota's seemingly rigid lean manufacturing system gained its flexibility and adaptability to changing circumstances [10]. A detailed description of lean principles and tools can be found in [2], [8], [9], and [11].

One of the widely known frameworks for implementing lean comprises five steps. The framework could be applied by any organization in order to move towards perfection by improving quality and eliminating waste in a systemic approach. The steps of this framework are [11]:

1. Identifying value: value should be determined as per the end customer of each type of product made or service provided by the organization.
2. Mapping the value stream: all steps (both value adding and non-value adding) involved in good production or service offering which comprise the related value stream should be identified so that the non-value adding steps can be eliminated whenever possible.
3. Creating continuous flow: products or services should flow smoothly toward the customer by arranging the value adding steps involved in a tight sequential manner.
4. Establishing pull system: make customers of downstream steps pull value from upstream steps of the created flow in order to synchronize the pace of production/ service delivery with the rate of customer demand.
5. Seeking Perfection: repeat the previous steps to continuously eliminate the waste identified in the value stream as a result of the current improvement cycle so that new goals for future improvement cycles toward perfection would be recognized.

However, this journey of lean transformation should have a starting point. Alukal and Chalice [9] suggest initiating the start of such journey by one or more of the activities listed below:

- Value stream mapping organizational processes to identify and eliminate non-value added activities.
- Conducting lean baseline assessment, through interviews, process observations, analysis of reliable data, and/ or informal flowcharting, will help identifying gaps from which the lean improvement plan could start.
- Mass training employees in lean, through various teach-do cycles, followed by immediate lean implementation.
- Implementing lean basic building blocks. These blocks include visual control, 5S, standardized work, point of use storage (POUS), and streamlined layout.
- Conducting a pilot rapid improvement project, Kaizen event, on a chosen bottleneck or constraint area in order to achieve breakthrough lean improvement.

- Initiating an organization wide change management that ensures aligning organization's strategies and employee goals followed by changing the traditional processes' push culture to lean pull.
- Developing a Pareto chart to analyze the overall equipment effectiveness (OEE) which may spot the biggest opportunities from which the lean journey should start.

Nonetheless, successful lean transformation is highly dependent on crucial organizational characteristics that form a healthy culture of lean environment. Some of these characteristics include respect for employees through everyone's involvement in the improvement process, limitless executive leadership commitment to pursue perfection, team-based continuous improvement activities, and good cultural change management during lean transformation [2], [9]. And most importantly, developing the right thinking way to identify the need and put the right countermeasure or solution to fulfill that need accordingly [2].

2.2. Lean application in hospitals

As healthcare systems, worldwide, are suffering from a rapid cost increase with considerable decline in quality of offered care, applying lean within these systems is a winning strategy. For instance, a major reason behind the increase of health insurance costs in the U.S. is running inefficient and ineffective processes within the current setup of healthcare providers [1]. The impact of this reason in inducing the observed increase in healthcare cost is considerably high compared to such reasons as introducing new advanced technologies and the aging population [1].

The total waste produced by healthcare providers in both non-patient care and patient care operations is assumed to be between 30 – 40 % of their total cost [1]. Improving both efficiency and effectiveness of these processes represent an opportunity for containing healthcare costs while improving the quality level of care delivered and enhancing both patients and staff satisfaction [1], [12]. Thus, lean is capable of helping healthcare providers "construct a hospital model that is simply centered on the patient, his or her physicians, nurses, and critical ancillary functions and that model contains little or no excess overheads" p. 40 [1].

As inferred from the conducted literature review, there are many successful cases of lean implementation in the healthcare area, as a strategy for the whole hospital [12] or on department level [13] – [16] in addition to the availability of reasonable material that covers lean transformation frameworks designed for the environment of healthcare organizations. See for instance [1], [9], and [16] –[22]. Yet, having healthcare institutes that implement the whole concept of lean aiming to achieve a world-class level of quality improvement and cost reduction is still rare.

2.3. Lean assessment tools and sustainability

There are many assessment tools, developed by researchers, to help lean implementing organizations assess their experience with adopting various lean practices and tools. See for instance [23]–[31]. Only the assessment tool in [31] is designed to be used by healthcare organizations while the former ones are designed to assess lean implementation in manufacturing firms. However, the developers of these assessment tools claim their applicability to service firms too.

All reviewed lean assessment tools have been developed with the aim of identifying the level of adopting this system within lean organizations. Most of these tools are designed to be used within a specific industry. Since lean is originated in the manufacturing industry, no wonder that most of these assessment tools are developed and geared to be used within this industry.

Due to the complex nature of lean resulting from the huge amount of interconnectivity among its concepts and various tools, the developers of lean assessment tools try to base them on a conceptualizing model that justifies categorizing number of lean practices under a set of organizational functional areas [23], [25]. By analyzing some of these assessment tools, it appears to be a common practice that both lean practices and functional areas are defined from literature and merged together according to the developed conceptualizing model. However, a variation has been observed in model conceptualization, which can obviously be linked to the various definitions of what lean is composed of.

As the set of constructs that define lean production has changed over the last two decades [25], lean assessment tools are expected to follow the norm too. After reviewing a set of lean assessment tools available in literature, Jørgensen et al. concluded that the good assessment tool should reflect the complex nature of lean in an accurate way [25]. Thus, such a tool should consider the two sets of variables which define the evolved nature of lean. These two sets represent, simultaneously, the variables of lean from a technical perspective, lean tools and practices, and an organizational perspective, lean culture development. Such characteristic is missing in many of the assessment tools available today [25]. As a result, Jørgensen et al. developed a lean capability model to help organizations assess their progress towards sustainable levels of lean implementation according to five different maturity levels. These levels are [25]:

- Sporadic production optimization,
- Basic lean understanding and implementation,
- Strategic lean interventions,
- Proactive lean culture, and
- lean in the extended manufacturing enterprise (EME)

Although this maturity model states both technical and organizational characteristics which organizations would have while being at any of the defined maturity stages, it does not provide an assessment mechanism by which an organization can identify its current level on the defined stages.

As compared to the number of lean assessment tools which have been developed in various manufacturing sectors, the availability of such tools to be utilized by healthcare organizations is relatively rare. One of these assessment tools is called “Lean Assessment for Hospitals” which has been developed by Leonardo Group Americas [31]. The tool is made of 80 (Agree/Disagree) questions under 16 different categories. These categories are:

- Staff communication,
- Visual hospital and organization,
- Staff cross-training and flexibility,
- Mistake proofing,
- Quick changeover,
- Quality systems,
- Supply chain management,
- Patient flow,
- Total productive maintenance,
- Pull systems,
- Standard work,
- Finance and accounting,
- Performance measurement,
- Patient communication, and
- Lean management system.

Using this tool, a group of hospital staff is expected to set together and answer all the questions in order to get a score out of 100 for each category. After that, the resulting scores are plotted in a radar chart format and an action plan is developed accordingly. Although the tool is designed to conduct lean assessment in hospital level, it is also promoted as a tool for assessing lean in department level. This is done by skipping those questions which do not apply to the assessed department(s).

2.4. Issues of lean sustainability in healthcare organizations

The ability of sustaining the achieved levels of improvement is a common concern addressed by many researchers investigating lean implementing healthcare organizations in the United State, the United Kingdom, and Canada. The Canadian literature about this concern identified strategy alignment, leadership, and behavior and engagement as the critical factors organizations should embrace to secure sustainability of the achieved results [18], [32]. A study about the National Health Services (NHS) experience with lean implementation in UK addressed the gap between sustainability and practical lean application [17]. The study suggested that leadership, communications, and workforce engagement are essential elements for lean successful implementation.

The U.S. literature states that respect for employees, executive leadership, continuous improvement teams, and empathetic change management are the foundations for a sustainable lean adopted system within healthcare industry [9]. Another view in the U.S. literature about what develops a sustaining lean organization is adopting a nested organizational structure which supports employee involvement and learning [1], [33]. This is achieved through encouraging front line staff to improve their processes, using scientific-based methodology, in a fair hassle-free environment supported by supervisors and managers at all levels of the organization. However, this requires high level of executive support, setting the organizational mindset about lean as a journey, not an initiative, to change the way of doing business, and creating team-based environment.

2.5. Literature review summary

Understanding the relationship between lean concepts and various lean activities and tools is essential for sustainable lean implementation. In addition, it leads to remarkable levels of performance improvement and cost reduction. Many researchers spent considerable efforts to help lean adopting organizations gain the best out of their experience by providing means for assessing lean implementation within their organizations. Due to the complexity of lean, the assessment tools are usually developed based on a model that conceptualizes lean main concepts and their related practices. However, the developed assessment tools do not usually assess both technical perspectives and organizational perspectives in a balanced way.

As lean started to be implemented in healthcare organizations, there is a need for assessment tools that help the implementing organizations measure the progress they do towards sustainable lean implementation. An effort has been made by Leonardo Group Americas [31] to provide healthcare organizations with an assessment tool that defines their current lean implementing stage and develop a roadmap to achieve better future stages. However, the tool does not address both lean perspectives in a balanced way.

Based on the literature review conducted, critical success factors for sustainable lean implementation in healthcare can be classified into the two main perspectives stated by Jørgensen et al. in [25] as follows:

- **Technical perspective**
    - Process stability
    - Process standardization
    - Patient flow streamlining (JIT)
    - Mistake proofing (JIDOKA)
    - Continuous improvement

- **Organizational perspective**
    - Leadership commitment
    - Culture and involvement
    - Respect for employees
    - Change management

3. Lean Sustainability Assessment Framework (LSAF)

As shown in Figure 1, the main objective behind developing and implementing sustainable lean-based processes in a healthcare organization is to enhance patient satisfaction through improving the quality of its offered services. Such improvement can be achieved by eliminating process waste and creating continuous flow based on patient's pull, rather than push, mechanism. The success of a hospital in developing and implementing lean-based processes as well as sustaining attained levels of resulting improvements is determined based on its progress in achieving higher levels of:

- developing stabilized processes with well determined steps and predictable outcomes,
- updating process standards based on newly gained knowledge and newly identified forms of waste,
- developing a continuous flow of products/ services among various organizational processes towards the patient,
- creating error proofing processes to do things right the first time,
- improving organizational processes according to newly defined forms of wastes,
- enhancing leadership commitment to support process improvement throughout the whole organization,
- developing the organizational culture which promotes the accountability of employees and support their involvement in the process of defining and achieving better process performance levels aligned with stated organizational objectives,
- respect for employees, and
- adopting constructive change management process while transforming to lean organizational setup.

Thus, using lean-based terminology, sustainable lean implementation is highly affected by the following two sets of factors:

- **Process factors** (factors that lead to process performance improvement while mastering various lean activities and tools):
    - Process stability
    - Process standardization
    - Patient flow streamlining
    - Mistake proofing
    - Continuous improvement

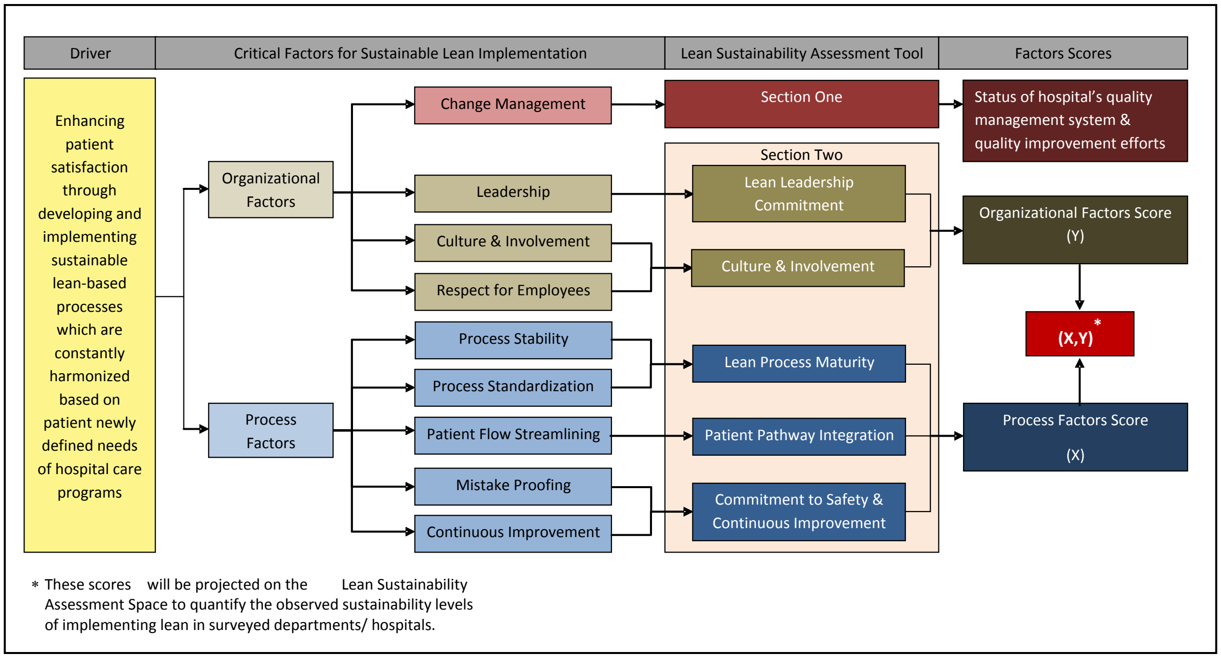


Figure 1. Lean sustainability assessment framework

- **Organizational factors** (factors that lead to enhance the organizational capabilities while developing staff cultural skills required to continuously improve the processes of their organization):
  - Leadership
  - Culture and involvement
  - Respect for employees
  - Change management

Based on these factors, components of the **Lean Sustainability Assessment Tool (LSAT)** of healthcare organizations have been constructed. While a detailed description of the LSAT is illustrated below, the tool itself is available in the format of an interactive PDF form upon request.

The LSAT is a balanced tool that evaluates the organizations' level of mastering lean activities and tools as well as the progress in developing lean-based cultural setup. It is made of two sections. These sections are:

- **Section one** which is addressed to quality management staff members of the hospital and includes questions about the level of intervention the surveyed hospital currently has with quality improvement initiatives, including lean, in addition to shading the lights on its status of accreditation/ certification. It also provides insight about the change management practices the surveyed hospital has adopted during its lean application journey. In order to make the developed tool usable for all hospitals, regardless of their level of lean adoption, respondents are directed throughout this section based on the current level of intervention with lean within their hospitals.
- **Section two** which is addressed to all staff members of the hospital and composed of five components covering both lean process factors and organizational factors except the "change management" factor which is

covered in section one. These components are:

- **Lean process maturity (LPM)**: includes 19 questions about process stability and process standardization. This component describes the ideal setup of various processes within the surveyed department/ hospital based on defined characteristics of ideal lean processes.
- **Patient/ specimen pathway integration (PPI)**: includes 16 questions about various patient flow streamlining activities. This component illustrates the ideal way of connecting various lean processes and the way of handling resource requests and demand fluctuation within the surveyed department as well as the whole hospital to create a continuous flow for patients/ specimens.
- **Commitment to safety and continuous improvement (CSCI)**: includes 21 questions about mistake proofing and continuous improvement. This component describes individual, departmental, and organizational ideal safety and continuous improvement attitudes while developing and updating lean processes within the whole hospital.
- **Lean leadership commitment (LLC)**: includes 15 questions about leadership. This component demonstrates the ideal leadership characteristics that must exist in order to have an effective hospital-wide implementation of lean.
- **Culture and involvement (CUIN)**: includes 28 questions about respect for employees and culture and involvement. This component presents the ideal cultural setup of a lean hospital as well as the level of involvement expected from various members of its organizational structure.

Questions under each component of this section are written in a five-point Likert scale format, and they have been generated based on the characteristics of sustainable lean implementation described in the literature [2], [9], [10],[16]–[22], [25], [34]. In order to make the developed tool ready for the analysis techniques proposed below, all questions of section two are coded in a positive direction (i.e. they represent the desired conditions resulting from proper implementation of lean). In addition to these questions, this section includes questions related to respondent’s position, department, and familiarity with lean activities and tools presented in a check-list format. For analysis purposes and based on their response about their positions, respondents of this section are classified into three categories: managers, supervisors, and department staff members.

The LSAT components of section two are used to determine the sustainability level of lean implementation within the surveyed hospital. Responses to the first three components (LPM, PPI, and CSCI) are combined to obtain the **process factors score** while the last two (LLC and CUIN) are combined to obtain the **organizational factors score** of the surveyed department/ hospital. These scores represent, respectively, the (x,y) coordinates of the surveyed department/ hospital in the **Lean Sustainability Assessment Space (LSAS)**. Depending on the values of these two scores of a department/ hospital, the sustainability of lean implementation in that department/ hospital can be in one of the four zones of the LSAS. As illustrated in Figure 2, these zones are:

- **Making progress zone**: where both process factors and organizational factors of sustainable lean implementation are considerably enforced within the analyzed organization,
- **Commencing zone**: where the organizational factors of sustainable lean implementation are more enforced than the process factors within the analyzed organization,
- **Confounding zone**: where the process factors of sustainable lean implementation are more enforced than the organizational factors within the analyzed organization, and
- **Critical zone**: where both process factors and organizational factors of sustainable lean implementation are insignificantly enforced within the analyzed organization.

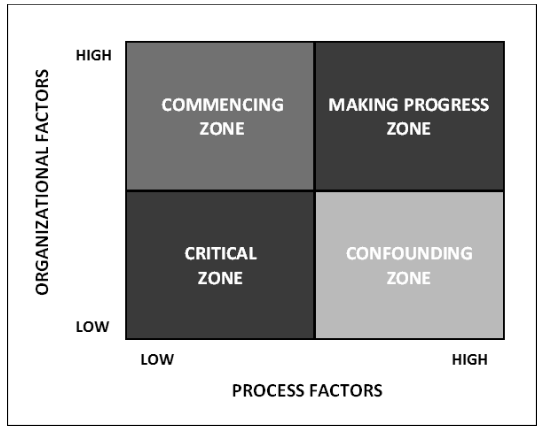


Figure 2. The LSAS

The making progress zone is the only zone in which healthcare organizations are considered to have a sustainable level of lean implementation where both process and organizational factors are significantly enforced within the organization. However, healthcare organizations in the remaining zones have unsustainable levels of lean implementation with different degrees of risk.

Organizations in the commencing zone encounter risk degrees less than those in confounding and critical zones. This is due to their high adoption level of organizational factors which have a significant effect in sustaining achieved improvements gained from implementing lean. Though, low adoption level of process factors reduces the effectiveness of improvement efforts conducted within these organizations. In order to move towards the making progress zone, these organizations need to master utilization of lean activities and tools through training and practice.

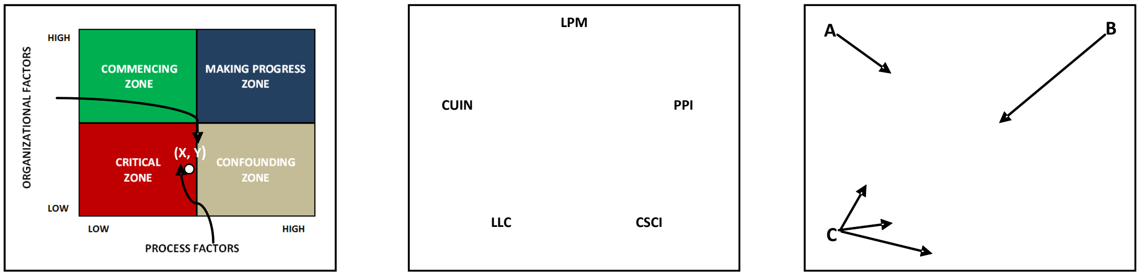
Despite the high adoption of process factors, lean improvement efforts conducted by organizations within the confounding zone are not so efficient due to the lack of adopting the organizational factors necessary for developing the organization capabilities of sustainable lean implementation. Staff members in such organizations suffer from high levels of frustration caused by the huge efforts of conducting lean-based improvement activities while not achieving satisfactory levels of performance. If the missing organizational factors are not properly enforced, the lean adoption within these organizations is probably going to fail. However, the probability of failure of lean implementation in these organizations is higher than those organizations in the commencing zone and lowers than those in the critical zone. Since organizations in the critical zone have low levels of adoption of both process and organizational factors, they highly suffer from unsustainable lean implementation and need serious efforts to move to the making progress zone.

In addition to providing factors' scores to locate a department/ hospital in the LSAS, the LSAT provides the surveyed department/ hospital with information about the level of adopting various characteristics of sustainable lean stated under each survey component of the developed assessment tool. This information is presented in a radar chart format for all survey components as well as the set of questions included under each one of them. Based on this information, current gaps of sustainable lean implementation are identified and a department/ hospital specific recommendations report is developed. This report is presented in a table format containing the desired conditions of various lean characteristics included in the LSAT in addition to their current level of implementation coded in icons format. Implementation of suggested action plan to each surveyed department should follow the priority order inferred from the coding in front of each lean characteristic of the recommendation report. A guide for reading the developed charts as well as the recommendations reports is illustrated in Figure 3.

4. Data Collection Setup

While data collected by first section of the LSAT is addressed to one of the quality management staff members in order to be used for stratification purposes and for finding out the effect of accreditation/ certification status and the level of adopting other quality improvement initiatives on the observed sustainability level of lean implementation, data collected by the second section of the assessment tool represents the major part of the conducted analysis. Components of this section are used to determine the sustainability level of lean implementation within the surveyed hospital. Such level is determined according to the level of implementing process factors and organizational factors within each department of the surveyed hospital. Data necessary for calculating the scores of these factors is collected according to the following steps:

- Each employee within each department fills in section two of the LSAT in order to obtain **individual rating of individual characteristics** of sustainable lean implementation within each hospital department.
- Employees' responses to each question of section two of the LSAT are combined for all those who work in the same department in order to obtain a **combined rating of individual characteristics** of sustainable lean implementation within a hospital department.
- Combined ratings of individual characteristics stated under the same survey component of the LSAT are combined to obtain a **combined rating of combined characteristics of each survey component** of sustainable lean implementation within a hospital department.



The LSAS	The LSAT radar chart	The LSAT radar chart of individual survey components
LSAS: Lean sustainability assessment space	**LSAT**: Lean sustainability assessment tool	
Definition: a two dimensional space that quantifies the level of implanting lean in surveyed departments/ hospitals.	**Definition**: a chart that shows the level of implementing each component of the developed assessment tool within surveyed departments/ hospitals.	**Definition**: a chart that presents the level of implementing lean characteristics of each LSAT component together with the level of dispersion observed in the reported levels of implementation.
Range: 0 – 1 for both process factors and organizational factors of sustainable lean implementation.	**Range**: 0 – 1 with a 0.2 increment presented in five pentagons.	**Range**: 0 – 1 with a 0.2 increment presented in five circles.
Surveyed departments/ hospitals are placed in one of the four LSAS zones based on the level of implementing these two sets of factors (X,Y).	**LPM**: Lean process maturity (i.e. how close the current setup of hospital processes is to ideal lean processes.)	**A**: level of implementing lean characteristics in surveyed departments/ hospitals.
Making Progress Zone: both factors are considerably enforced (i.e. X ≥ 0.5 & Y ≥ 0.5).	**PPI**: Patient/ specimen pathway integration (i.e. assessing the efforts of creating continuous flow of patients / specimens.)	**B**: level of dispersion observed in the reported adoption levels of lean characteristics.
Commencing Zone: organizational factors are more enforced than process factors (i.e. X < 0.5 & Y ≥ 0.5).	**CSCI**: Commitment to safety & continuous improvement (i.e. assessing members' attitudes while developing and updating hospital processes.)	**C:** radar chart data points. They vary based on number of questions of each LSAT component.
Confounding Zone: process factors are more enforced than organizational factors (i.e. X ≥ 0.5 & Y < 0.5).	**LLC**: Lean leadership commitment (i.e. assessing the effectiveness of leadership efforts in reaching hospital-wide lean implementation.)	If the level of dispersion (**B**) of the hospital ≤ 0.2, a single hospital's recommendations report needs to be generated.
Critical Zone: both factors are insignificantly enforced (i.e. X < 0.5 & Y < 0.5).	**CUIN**: Culture & involvement (i.e. assessing hospital's cultural setup and members' degree of involvement against lean ideal setups.)	If the level of dispersion (**B**) of the hospital ≥ 0.2, multiple departments' recommendations report need to be generated.

Rating Code	Description	Action Plan Order of Priority
	Agr (SA) ≤ 0.2	1
	0.2 < Agr (SA) ≤ 0.4	2
	0.4 < Agr (SA) ≤ 0.6	3
	0.6 < Agr (SA) ≤ 0.8	4
	Agr (SA) ≥ 0.8	5

Recommendations Report: a report that provides factors' specific recommendations based on current gaps of sustainable lean implementation that have been identified in the generated LSAT radar charts. This report is presented in a table format containing the desired conditions of various lean characteristics included in the LSAT in addition to their current level of implementation coded in colors and icons format. The table, on the left-hand side, shows both color and icon codes and action plan priority orders categorized by various levels of Agreement measures used to construct the related charts.

Figure 3. Charts reading guide

- The level of implementing **process factors within a hospital department** is obtained by combining the responses to survey components related to these factors (i.e. LPM, PPI, and CSCI). Likewise, the level of implementing **organizational factors within a hospital department** is obtained by combining the responses to survey components related to these factors (i.e. LLC and CUIN).
- Finally, responses of various hospital departments to survey components related to each set of factors are combined in order to determine **the level of implementing process factors and organizational factors in a hospital level.**

5. Data analysis techniques

According to the steps stated in section 4, the assessment process conducted by using section two of the LSAT can be classified as a multi-criteria group evaluation (i.e. decision making) setup. Thus, the analysis of the obtained data mandates the utilization of techniques capable of obtaining various sets of individual measurements, from each department member, and then combining them in various levels (i.e. individual characteristics level, survey components level, and set of factors level) to assess sustainability of lean implementation in either a department level or a hospital level. However, since the responses of all department members are collected in the Likert scale format, which is classified as ordinal data according to theory of measurement [35]; it seems to be infeasible to directly conduct such analysis. This is due to limitations on analysis techniques that could be performed on ordinal data.

As per Roberts [36], using the geometric mean to combine ratings of *n* different experts who rate a set of alternatives in various characteristics is considered a safe meaningful merging function (i.e. the obtained geometric means of experts' ratings can be used for alternatives comparison), provided that the ratings are in a ratio scale format. Thus, the collected data, using the above stated steps, can be analyzed by using the geometric mean if the employees' ratings, which are collected in a Liekert-scale format, are combined and presented in a ratio scale format. This can be done by using Consensus, Dissension, and Agreement measures which have been developed by Wierman and Tastle, over the last seven years, as mathematical measures that permit "a logical determination of dispersion around a category value" [37, p. 532] of Likert scale collected data to reflect the level of group agreement [37]–[39]. The three measures are common in providing a ratio scale measure, within the unit interval, about the agreement level of a population provided that the data have been collected using any ordinal scale among which is the Likert scale. However, the Consensus measure shows the level of population agreement in regards to the mean of the collected responses and the Dissension measure illustrates the level of dispersion in population collected responses around that mean of the categories of the Likert-scale response. Thus, these two measures are complement of each other (i.e. a complete consensus generate a Consensus measure value of 1 and a Dissension measure value of 0 and vice versa). In regards to the Agreement measure, it presents the level of population agreement with reference to a predetermined category of the Likert-scale response (e.g. strongly agree).

These measures have been originally developed within a group decision making setup [40] and have been utilized in various setups which use Likert scale-based data collection tools. See for instance [41]–[47].

The mathematical properties of Consensus and Dissension measures can be found in [37], [38], and [48] while various developmental stages and applications of the Agreement measure can be found in [39], [40], and [49]–[51]. In addition, Consensus and Dissension measures justification through deriving them from fuzzy logic basic formulas can be found in [52].

Consensus, Dissension, and Agreement measures are calculated based on the relative frequency distribution of received responses over Likert categories of each Likert item (i.e. each survey question) and the distances between these categories. When summing the responses of several Likert items (i.e. summing their relative frequencies on each Likert category), the Likert scale response is obtained.

For the purpose of this study, only the Agreement measure and the Dissension measure are going to be used. More specific, the Agreement measure will be utilized to find out the agreement level of hospital employees in regards to "Strongly Agree" target category while the Dissension measure will help in assessing the quality of the reported level of agreement through shading the lights on the dispersion level of the collected responses. In addition, the Agreement measure values will be used to generate process factors scores and organizational factors scores while the Dissension measure values will be used to determine the necessary levels of data analysis needed and the amount of recommendations which need to be provided.

The strong agreement of survey respondents to all questions of process factors or organizational factors will generate Agreement measure scores equal to 1 while their strong disagreement will generate scores equal to 0. If the responses are spread over the various categories of the Likert scale, the Agreement measure will have a value between 0 and 1. For the Dissension measure, the value of 1 indicates that 50% of the respondents are in the "Strongly Agree" category and 50% are in the "Strongly Disagree" category of the five-point Likert scale. The Dissension measure will have the value of 0 when a complete consensus is achieved by survey respondents in regards to the rated Likert item (i.e. only one Likert category is selected by all respondents). However, in order to be, at least, 95% confident that the observed level of agreement is reached with a consensus level of 80% or more, the Dissension measure value must not exceed 20% [46]. Whether or not the observed level of dispersion is ≤ 20% (i.e. within the inner circle of the radar chart of the individual survey component) determines the level of analysis required to identify the level of implementing sustainable lean characteristics within the departments of a surveyed hospital. For instance, if a hospital has a Dissension measure equals to 20% for all LSAT components, it can be inferred that:

- the hospital staff members have a significant level of agreement, more than 80% with 95% confidence level, about the current level of implementing lean characteristics in their hospital,
- the hospital radar chart, which illustrates the level of implementing process factors and organizational factors categorized by lean characteristics of each survey component, can be used to represent level of implementing these factors in each department of the hospital, and
- only one set of recommendations needs to be provided to all departments of the hospital.

If the observed dispersion level is more than 20%, more analysis will be needed to identify the sources of variation that have been observed and department-specific recommendations will be generated accordingly.

The reason of using the Dissension measure, instead of the Consensus measure, in assessing the quality of the reported level of agreement is that the value of Dissension measure directly indicates the level of dispersion in the received responses without the need of stating any central tendency related information. This is not the case with the Consensus measure (i.e. if we say the team has reached 80% level of consensus, we need to know on which category but this not needed when reporting the value of the Dissension measure). In order to confirm this property of Tastle and Wierman Dissension measure, it has been compared with Leik's dispersion measure. This measure is described as "the purest ordinal measure of spread" [53, p. 67] since it's obtained from the cumulative relative frequency distribution of responses over a set of ordinal categories independent of "sample size, number of choice options, central tendency, and assumptions about intervals between choice options." [54, p. 86]. Although the Dissension measure is calculated from the relative frequency distribution, not from the cumulative relative frequency distribution as Leik's Dispersion measure is calculated, both measures show no significant statistical difference in the dispersion level observed in a set of simulated Likert category responses at level of 0.05 α of Wilcoxon Signed rank test.

Based on these properties of Tastle and Wierman measures, these measures can transfer team members' evaluation of multiple alternatives collected in Likert scale (i.e. ordinal) format into ratio scale format. Therefore, it will be safe to use the geometric mean of Agreement measure and Dissension measure resulting from combining the ratings of department employees and use them to determine the level of factors implementation within their department/ hospital. The remaining part of this section shows how this is applied throughout the study by using a hypothetical example. It also shows that the Agreement measures and Dissension measures obtained by summing the responses on several Likert items (i.e. summing their relative frequencies on each Likert category) to provide the level of implementing a combined set of lean characteristics can generate values equal to those obtained by getting the geometric mean of the Agreement measures of the Likert items included.

A total of 80 staff members working at the X department of hospital Y have responded to a survey instrument about the level of implementing lean within their department. The instrument is made of five components (i.e. Likert scales) each of which contains three questions (i.e. Liker items). Responses of staff members have been captured using five-point Likert categories (i.e. SD, D, N, A, SA) and a frequency table has been generated by tallying the number of responses per category for each question. Both Dissension measure and Agreement measure have been calculated for each question. Since all questions of the survey instrument are written in a positive tone, the "SA" category has been selected as the target category used to calculate the Agreement measure. The obtained values of both measures are presented separately in Tables 1 and 2. In addition, Table 1 shows the Agreement measure for each survey component as well as each framework factor. Values of these measures are obtained by calculating the geometric mean of the measures of the related questions.

For instance, the Agreement measure value of the strongly agree category of the Likert scale Agr(SA) of LPM survey component is obtained by getting the geometric mean of Agr(SA) of LPM1, LPM2, and LPM3 while Agr(SA) of the process factors is obtained by getting the geometric mean of all Agr(SA) of LPM, PPI, and CSCI questions.

However, **tallying the staff members' responses to each survey component and each framework factor, instead of each survey question**, represent another way to obtain the corresponding Agr values. This method will be denoted as the frequency distribution method of obtaining Agr values. Table 3 presents the obtained values using this method together with the values obtained by using the geometric mean.

According to Wilcoxon Signed rank test, the values obtained by these two methods have no significant statistical difference at 0.01 α.

The comparison between the two methods has been performed to support the use of the frequency distribution method in obtaining the values of Agr which is originally used by Tastle and Wierman in almost all of their papers. Not observing significant statistical difference among Agr values obtained by geometric mean method and frequency distribution method makes the later a safe technique for combining ratings of *n* different experts who rate a set of alternatives in various characteristics as the former is considered so by Roberts [36].

Nonetheless, in order to use these measures on the collected responses using this method, the following conditions need to be satisfied:

- All questions of section two of the developed LSAT should be written in a positive tone.
- The Cronback's Alpha of each survey component is 0.7 or more [55], [56].

- The Cronback's Alpha of Process Factors components combined is 0.7 or more.
- The Cronback's Alpha of Organizational Factors components combined is 0.7 or more.

6. LSAT Validation and Framework Implementation

A common definition of validity among researchers using survey instruments in their studies "is the extent to which the survey measure accurately reflects the intended construct." [57, p. 254] However, there is no specific method agreed upon for evaluating the validity of a developed survey instrument [55], [57]. Nonetheless, there are several methods used traditionally to validate a developed survey tool. These methods are [55]:

- Criterion validity,
- Content validity,
- Construct validity,
- Convergent validity, and
- Discrimination validity

For this research, the content validity method has been used to assess the validity of questions included in the developed survey tool. Using content validity method, the survey instrument is assessed by subject matter experts to find out to which extent it measures the various aspects of the underlying concept [55]. By following Groves et al. [57] recommendations for developing attitude questions and self-administered questionnaires in addition to subject matter expert's comments about the suitability of the content of the initial version of the LSAT for the objective of the research, the final version of the tool was developed. In this version, the first section of the LSAT is formed of eight questions while the second section is formed of 99 questions, distributed over five components, with titles and wording suitable for healthcare organizations.

The ideal case of utilizing the developed LSAT mandates the participation of all hospital staff members to:

- ensure their involvement in the implementation process and
- reflect their level of commitment towards achieving sustainable levels of lean implementation.

However, the objectives of this research can be achieved through using the convenient sampling technique to identify the respondents to both sections of the developed assessment tool.

The population of the research is formed of all managers working at one of the non-profit hospitals in Florida. The hospital has more than 500 beds and more than 600 physicians. The total number of managers working at the hospital is 235. Using the convenient sampling technique, two members of the quality management department have been selected, to respond to the first section of the assessment tool, while 55 managers have been identified, to respond to the second section of the tool.

Both sections of the developed tool have been prepared in an interactive PDF format in order to be distributed and returned through e-mail. The data was collected over a two-month period. During that period and, two reminders were e-mailed to survey respondents and two data collection sessions were conducted at one of the computer rooms at the hospital. The response rate to LSAT section one is 100% (total sample size is two) while the response rate to section two is 25.5% (total sample size is 55) representing 13 different departments of the hospital.

Table 1. Agreement measure of dept. X

Likert Items	Likert Categories					Agr(SA)	Survey Components	Geometric Mean Agr(SA)	Framework Factors	Geometric Mean Agr(SA)
	SD	D	N	A	SA					
LPM1	13	22	16	12	17	0.54	LPM	0.54	Process	0.54
LPM2	9	19	15	21	16	0.60				
LPM3	19	21	13	14	13	0.48				
PPI1	19	17	20	13	11	0.48	PPI	0.52		
PPI2	12	15	18	20	15	0.58				
PPI3	21	13	17	11	18	0.51				
CSCI1	13	16	18	14	19	0.57	CSCI	0.57		
CSCI2	17	18	10	15	20	0.55				
CSCI3	8	22	17	18	15	0.58				
LLC1	19	17	10	21	13	0.52	LLC	0.54	Organizational	0.54
LLC2	11	21	16	16	16	0.56				
LLC3	16	15	15	17	17	0.55				
CUIN1	14	15	18	16	17	0.57	CUIN	0.54		
CUIN2	18	14	12	15	21	0.56				
CUIN3	19	13	20	15	13	0.51				

Table 2. Dissension measure of dept. X

Likert Items	Likert Categories					Dnt
	SD	D	N	A	SA	
LPM1	13	22	16	12	17	0.55
LPM2	9	19	15	21	16	0.52
LPM3	19	21	13	14	13	0.58
PPI1	19	17	20	13	11	0.54
PPI2	12	15	18	20	15	0.52
PPI3	21	13	17	11	18	0.62
CSCI1	13	16	18	14	19	0.56
CSCI2	17	18	10	15	20	0.64
CSCI3	8	22	17	18	15	0.50
LLC1	19	17	10	21	13	0.60
LLC2	11	21	16	16	16	0.53
LLC3	16	15	15	17	17	0.58
CUIN1	14	15	18	16	17	0.55
CUIN2	18	14	12	15	21	0.64
CUIN3	19	13	20	15	13	0.55

Table 3. Frequency distribution-based vs. geometric mean-based values of Agr measure

Likert Scales		Likert Categories					Agr(SA)	Geometric Mean Agr(SA)
		SD	D	N	A	SA		
Survey Components	LPM	41	62	44	47	46	0.54	0.54
	PPI	52	45	55	44	44	0.53	0.52
	CSCI	38	56	45	47	54	0.57	0.57
	LLC	46	53	41	54	46	0.54	0.54
	CUIN	51	42	50	46	51	0.55	0.54
Model Factors	Process	131	163	144	138	144	0.54	0.54
	Organizational	97	95	91	100	97	0.54	0.54

Since responses to section two of the LSAT are used to quantify the sustainability level of lean implementation in hospitals, the reliability analysis has been performed only on this section of the developed assessment tool. Based on the responses received to this section, the reliability measures of its various components have been calculated using the Cronbach's alpha (α) coefficient of internal consistency. As illustrated in Table 4, all Cronbach's α values are greater than 0.7. This indicates that the developed items of these components are highly reliable in measuring the underlying defined constructs.

However, the omitted item statistics, conducted by Minitab, showed low (<0.3), high (>0.8), and negative item adjusted total correlations of some of the items included under various components of the survey [58]. Number of these items is shown in Table 5 and they indicate, respectively, item's low, multicollinear, and reverse coded correlation with the sum of all remaining items included in Cronbach's α calculation [58]. Nonetheless, omitting these items from the developed survey instrument did not show significant improvement in observed values of Cronbach's α. Thus, these items were included in the analysis due to the valuable information they represent in lean implementation assessment process.

Based on the presented values of Cronback's alpha and since all items of section two of the LSAT are written in a positive tone, those conditions stated at the end of section 5, which are required to use the proposed data analysis techniques, have been satisfied.

The remaining part of the section illustrates, breifly, the results of applying the developed framework in the analyzed hospital. However, a detailed presentation of the obtained results of the assessment, espiaially those related to data collected by section one of the LSAT, will be presented in a future paper.

According to the received responses to section two of the LSAT, the hospital location in the LSAS is at the lower left corner of the making progress zone, Figure 4, with 0.58 process factors score and 0.65 organizational factors score. These levels are determined according to the level of responding managers' agreement about the status of adopting lean characteristics that lead to sustainable lean implementation within their hospital. Being located within this zone of the LSAS shows the significant commitment the hospital has to progress towards achieving sustainable levels of lean implementation. Nonetheless, as shown in Figures 5 and 6, the hospital has potential opportunities for improvement since some of the essential characteristics of such implementation are less adopted and needs to be reinforced.

Figure 5 shows the hospital's adoption status of these characteristics classified by various LSAT components while Figure 6 is a detailed illustration of the adoption status of all lean characteristics stated under each LSAT component (i.e. the outer light gray area). In addition, this figure shows the level of dispersion observed in the reported lean characteristics levels of adoption throughout the whole hospital (i.e. the inner dark gray area).

From Figure 5, it can be inferred that lean characteristics related to various LSAT components are equally implemented with a nearly 0.6 (or 60%) score. When looking at Figure 6, it can be seen that the level of implementing characteristics related to lean process maturity (LPM) varies from 40% to less than 80% with LPM3, LPM7, LPM10, and LPM14 as the least adopted characteristics and LPM16, and LPM18 as the most adopted ones.

In addition, Figure 6 shows that lean characteristics related to patient/ specimens pathway integration (PPI) are implemented with a level close to 60 % except for PPI2, PPI9, and PPI13, which do not exceed 40% and PPI3, which reaches 80%. Moreover, Figure 6 illustrates an almost 60% level of implementation of lean characteristics of the commitment to safety and continuous improvement (CSCI) LSAT component except for those related to CSCI17, CSCI18, CSCI19, CSCI1 and CSCI12, which range from 75% to 80%, and CSCI2, which does not exceed 40%.

In regards to those characteristics related to lean leadership commitment (LLC) component of the LSAT, Figure 6 shows a range of adoption levels between 60% and 80% with LLC6, LLC8, LLC11, LLC12, and LLC17 as those characteristics which are highly adopted. Likewise, lean characteristics of culture and involvement (CUIN) component of the assessment tool have a level of adoption ranges from 60% to 80% except for CUIN24 (<50%), CUIN27 (around 40%), CUIN26 (30%), and CUIN25 (20%).

So far, the presented analysis provided a quantified view about sustainability of lean implementation in hospital A using the developed framework. It showed both well adopted and least implemented characteristics which are common to all hospital departments. However, recommendations about what to do to move towards higher levels of sustainability should not be made prior to investigating the level of responding managers' agreement about the observed scores of the evaluated factors. Such investigation might reveal the necessity of conducting further analysis on department level and providing department-specific recommendations to each department of hospital A participating in the assessment process.

By looking at the level of dispersion observed in the reported lean characteristics levels of adoption in hospital A, the inner dark gray areas of Figure 6, a separate analysis needs to be conducted for each department in order to determine department-specific sets of recommendations. This is because the observed level of dispersion is more than 20% (i.e. outside the inner circle of the radar chart) for most of the lean characteristics of the LSAT components.

Figure 7 presents the LSAS of all surveyed departments based on the calculated factors scores. According to the factors scores shown in this figure, nine of the surveyed hospital departments are located within the making progress zone, three within the commencing zone, and one within the critical zone of the LSAS.

Table 4. Reliability Analysis of the LSAT

Component Name	Cronbach's α	Factors Group	Cronbach's α	Cronbach's α of the Assessment Tool
Lean Process Maturity (LPM)	0.917	Process	0.953	0.968
Patient/ Specimen Pathway Integration (PPI)	0.938			
Commitment to Safety & Continuous Improvement (CSCI)	0.871			
Lean Leadership Commitment (LLP)	0.902	Organizational	0.932	
Culture & Involvement (CUIN)	0.860			

Table 5. Number of low, high, and negative item adjusted total correlations as per the omitted item statistics conducted by Minitab

Component Name (Number of Items)	Number of Items with Low Item Adjusted Total Correlation (<0.3)	Number of Items with High Item Adjusted Total Correlation (>0.8)	Number of Items with Negative Item Adjusted Total Correlation
Lean Process Maturity (19)	None	2	None
Patient/ Specimen Pathway Integration (16)	2	5	None
Commitment to Safety & Continuous Improvement (21)	2	None	None
Lean Leadership Commitment (21)	3	1	None
Culture & Involvement (28)	7	None	1
Process Factors (LPM, PPI, CSCI) (56)	6	1	3
Organizational Factors (LLC, CUIN) (49)	6	None	2

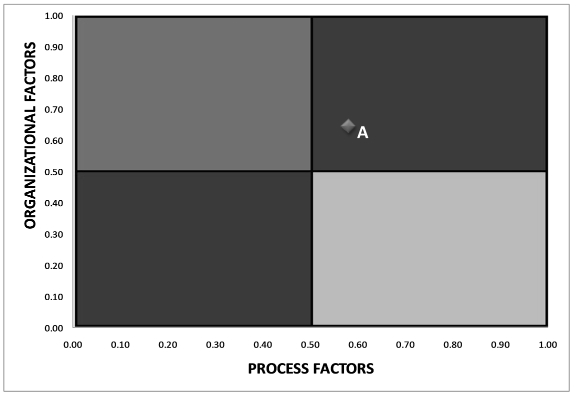


Figure 4. The LSAS of hospital A

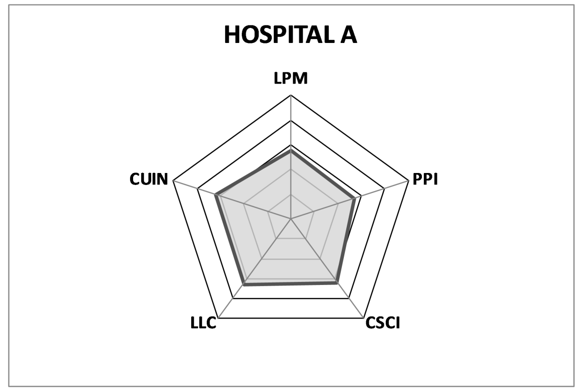


Figure 5. The LSAT radar chart of hospital A

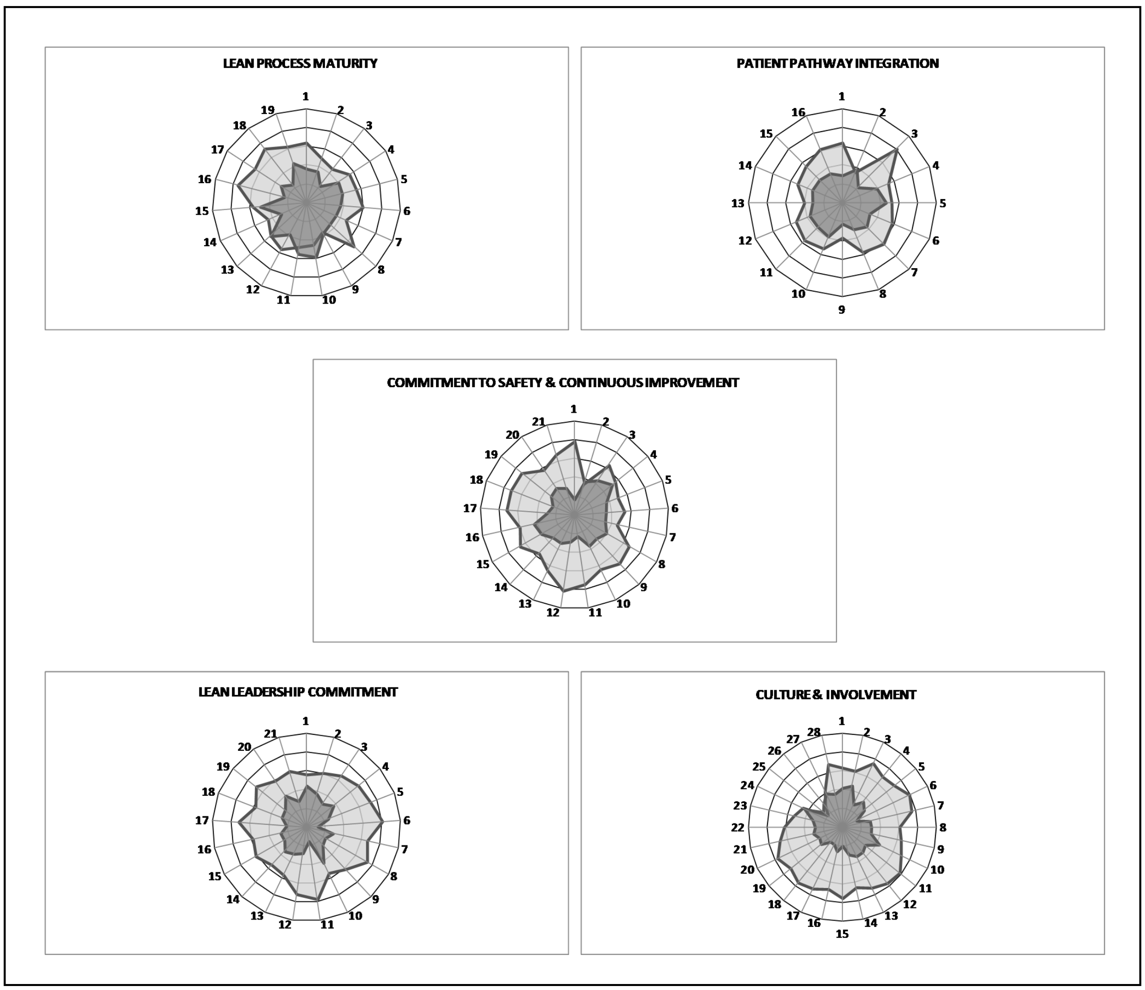


Figure 6. The LSAT radar chart of hospital A individual survey components

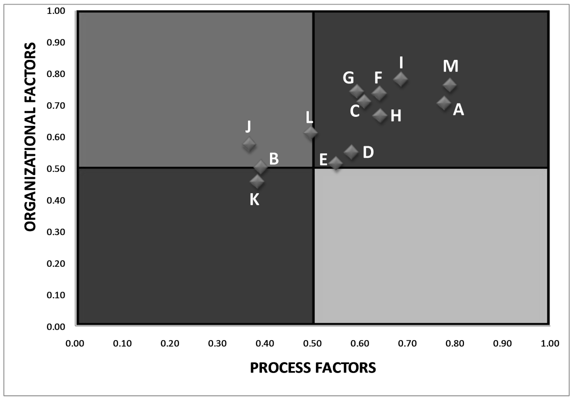


Figure 7. The LSAS of hospital A participating departments

Among those departments in the making progress zone, departments M and E have, respectively, the highest and the lowest observed scores. Other departments in this zone have different combinations of process factors and organizational factors scores between the scores of these two departments. However, the range of variation of both factors scores is nearly identical (i.e. between 0.5 and 0.8). When comparing those departments which are spread over the commencing zone, it can be seen that department L has the highest level of both factors adoption while departments J and B supersede each other in the level of adopting one of the factors' groups. Figure 7 also shows that department K is located in the critical zone with a nearly 0.4 process factors score and 0.45 organizational factors score. This observed variation in reported factors scores of hospital A departments confirms the necessity of providing department-specific sets of recommendations.

In order to statistically validate the significance of lean sustainability levels obtained by the developed framework for all departments of hospital A, a set of nonparametric Friedman tests was conducted on observed factors scores. The results of these tests are summarized in Table 6. By alternating the number of blocks between number of factors' scores (2), number of survey components (5), and total number of lean characteristics of all survey components (105), the p-values of these tests vary for the departments that have been analyzed. However, it can be confidently said that the observed variation in these scores is statistically significant at $\alpha=0.05$.

7. Conclusion

Despite the value of adopting lean within healthcare organizations, the rate of applying these practices in this sector is slower than it should be. In addition, it has been accompanied with enormous obstacles related to proper lean implementation, sustainability of achieved levels of performance, and staff engagement in infinite cycles of continuous improvement towards perfection.

This paper proposed a framework to help healthcare organizations quantify their experience with lean. Such quantification is obtained by measuring the agreement level of hospital staff members about the degree of adopting two sets of critical factors of successful lean implementation within their hospital. The proposed framework has been validated by determining the sustainability level of lean implementation within one of U.S. hospitals in State of Florida.

The analysis presented throughout this paper demonstrated the usefulness of the developed framework in quantifying sustainability of lean implementation on hospital and individual department levels. It also showed how to determine the extent of analysis which needs to be performed based on the observed level of dispersion in the received responses.

Table 6. Friedman test p-values of various framework obtained results

The Null Hypothesis	Number of Treatments	Number of Blocks	DF	P Value
Factors scores of all departments are identical (Blocked by process factors scores and organizational factor scores)	13	2	12	0.044
Factors scores of all departments are identical (Blocked by survey components)	13	5	12	<0.001
Factors scores of all departments are identical (Blocked by individual Lean characteristics under all survey components)	13	105	12	<0.001
Factors scores of all departments in the Commencing zone (B, J, L) are identical (Blocked by survey components)	3	5	2	0.022
Factors scores of all departments in the Contentment zone (A, C, D, E, F, G, H, I, M) are identical (Blocked by survey components)	9	5	8	0.022
LPM scores of all departments are identical (Blocked by individual Lean characteristics under LPM survey component)	13	19	12	<0.001
PPI scores of all departments are identical (Blocked by individual Lean characteristics under PPI survey component)	13	16	12	<0.001
CSCI scores of all departments are identical (Blocked by individual Lean characteristics under CSCI survey component)	13	21	12	<0.001
LLC scores of all departments are identical (Blocked by individual Lean characteristics under LLC survey component)	13	21	12	<0.001
CUIN scores of all departments are identical (Blocked by individual Lean characteristics under CUIN survey component)	13	28	12	<0.001

8. Future work

As data collected by section one of the LSAT was not presented in this paper, they will be illustrated in a future paper. More specific, the illustration will be made about some of the aspects related to the observed levels of lean sustainability in the analyzed hospital in the content of those information gathered by section one of the LSAT (i.e. status of hospital's A quality management system and quality improvement efforts).

In addition, the presented results of framework utilization are based on data collected from one hospital. Therefore, collecting data from more than one hospital should be considered in future studies in order to explore the framework benchmarking capabilities in hospital level and provide more insight to framework validation and LSAT reliability verification. In addition, collecting larger number of responses will justify the exclusion of LSAT items with low, high, or negative item adjusted total correlations which were not excluded in this study.

Finally, after developing appropriate sets of survey questions, the developed framework has the potential to be used in future studies for assessing six sigma maturity as well as quality management maturity for Malcolm Baldrige National Quality Award criteria.

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